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PRELIMINARY DESIGN STUDY OF AN INTEGRATED TAIL ROTOR SERVO POWE--ETC(U)
SEP 77 J R MACIOLEK, K WALLISCHECK DAAJ02-76-C-0056
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PRELIMINARY DESIGN STUDY OF AN INTEGRATED TAIL ROTOR SERVO POWER MODULE

Sikorsky Aircraft Division
United Technologies Corporation
North Main Street
Stratford, Conn. 06602

September 1977

Final Report

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Prepared for

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EUSTIS DIRECTORATE POSITION STATEMENT

This report provides preliminary design study results which indicate that a control actuator with integral hydraulic power supplies can be successfully utilized for tail rotor control of a utility helicopter. Sufficient hydraulic power generation and regulation capability for two control stages can be packaged within the tail rotor gearbox envelope restrictions of the YUH-60A current technology utility helicopter.

Results of this contractual effort are still preliminary and additional effort is required to improve and validate the survivable characteristics of the design. Mr. Harold Holland of the Military Operations Technology Division served as technical monitor for this effort.

DISCLAIMERS

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of the work performed was to determine the feasibility of generating the hydraulic power required to control the tail rotor pitch of a utility helicopter by locating tail-rotor-driven hydraulic supply systems within the tail rotor servo. This relocation of the hydraulic supply system would eliminate the weight, the cost and the excessive vulnerability of the long hydraulic lines in conventional servo systems. → next page

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20. ABSTRACT (Cont'd)

Using the YUH-60 as a design subject, a preliminary design of an integrated servo power module with electrical (fly-by-wire) inputs was performed. A mechanical-input version of this servo was also studied. The attributes of these integrated servo power modules were compared with those of the current baseline YUH-60 system and a conventional fly-by-wire system. Assembly drawings of the fly-by-wire and mechanical-input versions of the integrated servo power module and detailed descriptions of their components were prepared and are presented.

This study confirms the advantages of generating the hydraulic power at the tail rotor gearbox. When combined with a fly-by-wire controller, the weight saving for a UTTAS design would be the order of 10 lbs. Compared with the current conventional system, the MTBF of the system would increase by a 7 to 1 factor. Production cost savings could be almost $2000 per aircraft.

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INTRODUCTION

This report presents the results of a preliminary design study of an integrated tail rotor servo power module for use in a utility helicopter. The unique feature of this servo is the dual tail-rotor-driven hydraulic-power supply system, which is integral to the servo module and is located within the tail rotor gearbox housing. The initial impetus for this study was the potential weight savings and vulnerability reduction achieved by eliminating the hydraulic lines delivering power from the main rotor to the tail rotor. This study investigated the improvements that may be realized with this tail rotor servo concept.

The design study used the tail rotor control requirements of the YUH-60 as representative of the requirements of a modern utility helicopter. Two versions of the integrated tail rotor servo were designed to these requirements. The first is an electrical input (fly-by-wire) servo whose output displacement is proportional to electrical command inputs. The second is a mechanical input servo whose output displacement is proportional to a mechanical input motion. The attributes of each version were compared with the current YUH-60 mechanical input servo and a state-of-the-art fly-by-wire configuration with an electrohydraulic control actuator driving the current YUH-60 mechanical input servo.

A design specification for the integrated tail rotor servo, both the fly-by-wire and the mechanical input versions, is presented in Appendix A.

DETAILED DESCRIPTION

The integrated tail rotor servo power module is designed for operation in either a fly-by-wire tail rotor control system or in a conventional mechanical system. The servo is a two-stage unit and is comprised of three major elements in each stage: the actuator ram, the hydraulic power supplies, and the flow-control elements. The YUH-60 performance requirements are met by either configuration. The actuator ram and the hydraulic power supplies are identical for both configurations. The flow-control portion of the fly-by-wire configuration contains all the electrical and electrohydraulic components, including the feedback circuitry. The flow-control portion of the mechanical version includes the mechanical input, the feedback and the servovalve drive linkage.

MECHANICAL INPUT CONFIGURATION

The mechanical input version of the integrated servo has been designed as a direct replacement of the current YUH-60 tail rotor servo. The current tail rotor control system of the YUH-60 is a conventional mechanical control system that requires an output displacement of the hydromechanical tail rotor servo to position the tail rotor's blade pitch. Figure 1 is a block diagram of the YUH-60 tail rotor control system. The pilot's pedal motions are mechanically summed with the output of the yaw Stability Augmentation System (SAS). A pilot boost servo prevents SAS inputs from backdriving the pedals. The resultant pedal/SAS control motion is summed with collective motion in the mixer to provide torque reaction to power changes. This mixed output is then sent to the tail rotor via a redundant mechanical control cable linkage. The tail rotor command is also summed with the longitudinal main rotor control in the mixer. This mixing prevents the vertical component of tail rotor thrust from upsetting the pitch attitude of the helicopter as yaw-control inputs are applied to the tail rotor. Two hydraulic supply pressures are piped from their origin at the main-rotor-transmission driven hydraulic pump and the electric-motor-driven hydraulic pump to the tail rotor servo, located in the tail rotor gearbox. The mechanical input version of the integrated tail rotor servo directly replaces the mechanical function of the current YUH-60 servo without the need for the external hydraulic supplies, thus reducing system weight and vulnerability.

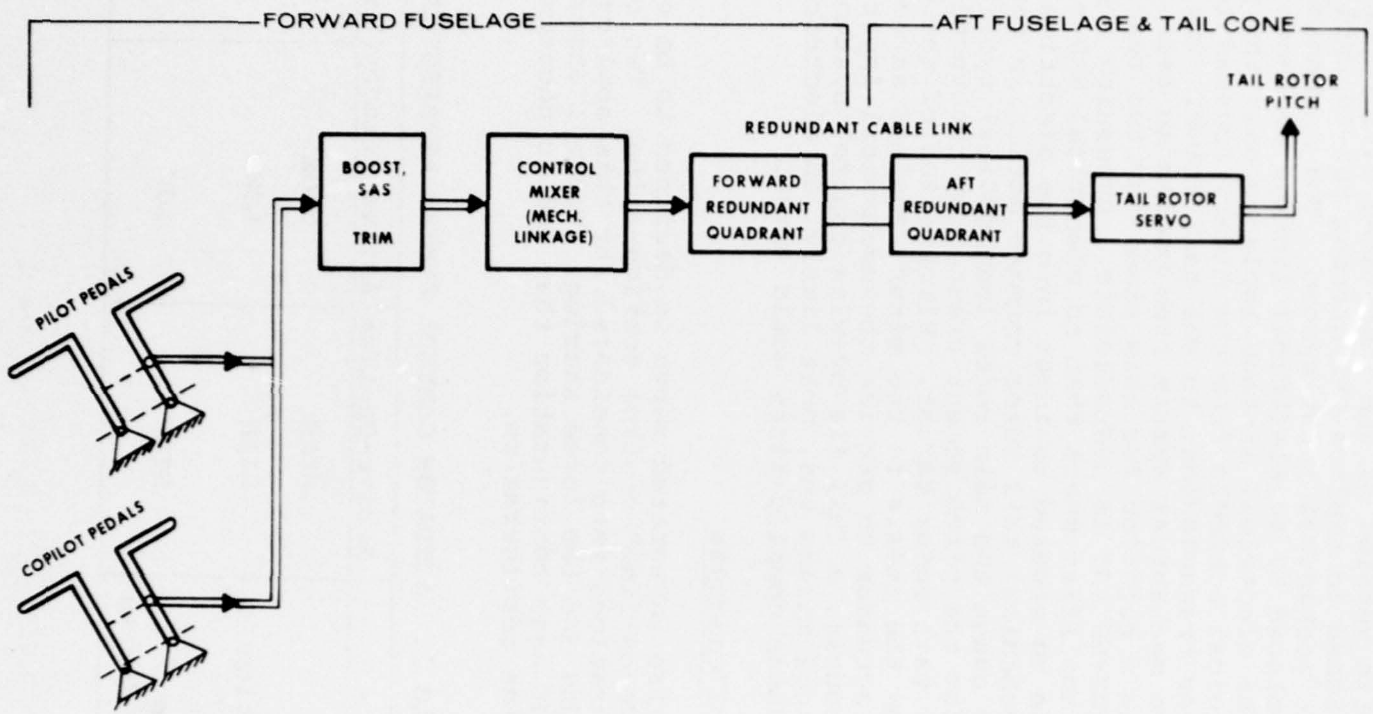


FIGURE 1. EXISTING YUH-60 TAIL ROTOR CONTROL SYSTEM.

FLY-BY-WIRE CONFIGURATION

The fly-by-wire version of the integrated tail rotor servo has been designed to replace the current YUH-60 tail rotor servo and the mechanical input system. The mechanical input system is replaced by an electrical linkage as shown in Figure 2. The electrical linkage replaces only the portion of the mechanical controls from the mixer, located in front of the main rotor transmission, to the tail rotor. Replacement of the entire mechanical system from pedals to tail rotor was not chosen as a solution for this study for two reasons. First, the YUH-60 SAS is hydrofluidic. Bypassing the hydrofluidic SAS amplifier means that an electrical SAS signal would have to be created to input into the electrical link. Second, a mechanical tail rotor command motion is required at the mixer to cause the main rotor longitudinal cyclic to compensate for the pitch moment created by the vertical component of tail rotor thrust. Elimination of the mechanical linkages from the pedals to the mixer requires an additional fly-by-wire actuator to provide the mechanical input to the mixer. Of course, a full fly-by-wire control system would have electrical mixing and, most likely, an electrical SAS, and neither of these complications would exist.

Servo Control Concepts

The fly-by-wire integrated servo is designed to be operated in an "active-on-line" control configuration. Two other control configurations were considered for this application, the active standby and the force sharing. Table 1 shows the attributes of each configuration that led to choosing the active-on-line configuration.

TABLE 1. ACTUATOR CONTROL SYSTEM ATTRIBUTES

Attributes	Active-On-Line	Active Standby	Force Sharing
Stiffness	HIGH	HIGH	LOW
Fault Detection Capability	HIGH	LOW	HIGH
Tolerance to Undetected Faults	HIGH	LOW	HIGH

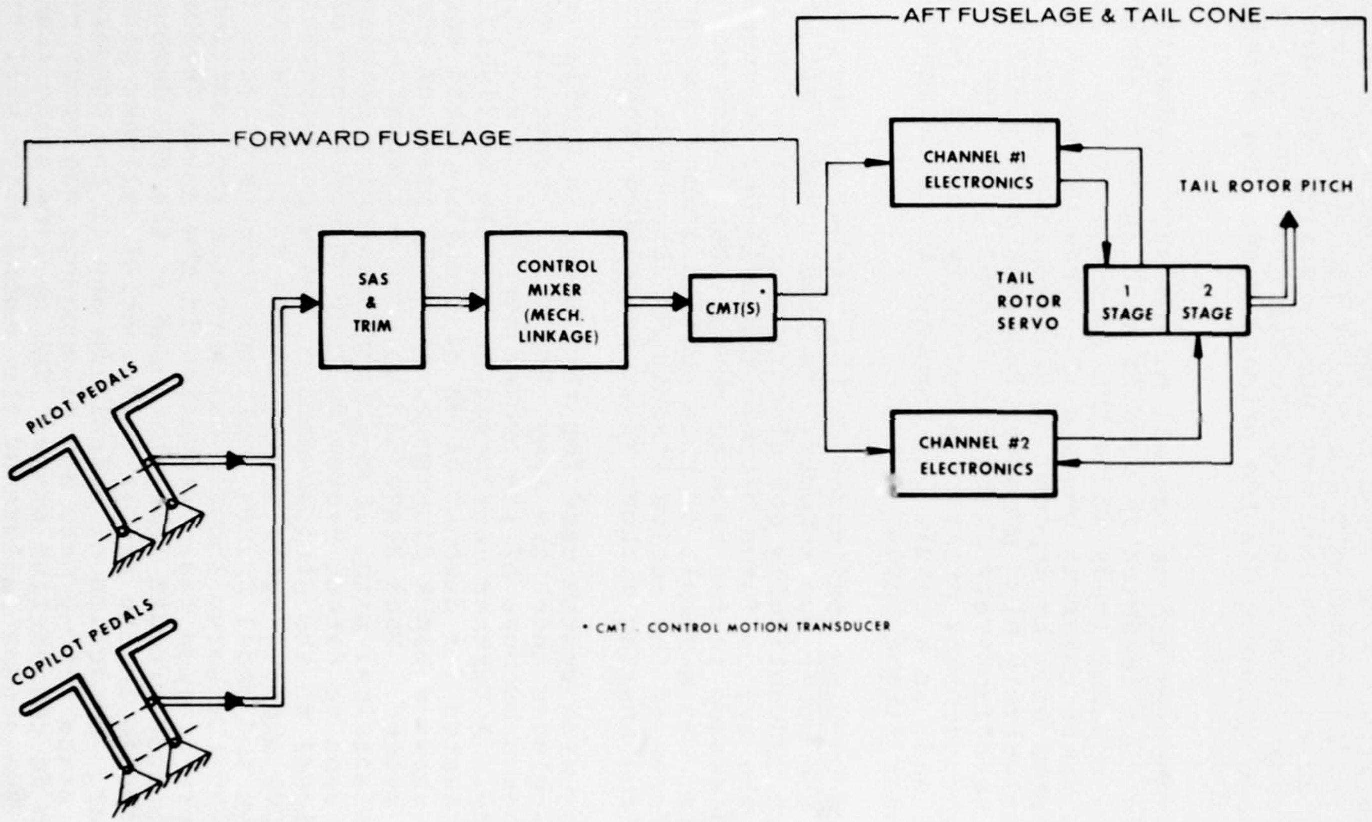


FIGURE 2. YUH-60 TAIL ROTOR ELECTRICAL CONTROL SYSTEM.

The Active Standby scheme has all of the servo stages except one turned off. The remaining active stage provides the control capability. A detected failure of the active stage causes it to be turned off and one of the standby stages to be turned on to become the new active stage. The dependence on the bypass valve to turn on the standby stage to overcome active-stage failures was the primary reason for eliminating this configuration.

The Force Sharing scheme has all of the servo hydraulic stages "ON." Pressure feedback is used in each stage to equally divide the control loads among the actuator stages. This scheme is fault tolerant because the force generated by the failed system will be opposed by the remaining stages. However, a relatively high pressure feedback gain would be required to effectively share the control load. This high gain on the actuator pressure effectively reduces the servo stiffness and, as a result its response to high-frequency SAS inputs under flight loads.

The Active-On-Line configuration has neither of the major drawbacks of the other two schemes. In this scheme, all of the stages are hydraulically and electrically active, but only one produces the system force because the cylinder pressure of the remaining stages is fed back to reduce their force producing capability. As a result of this configuration, the servo has the stiffness of the active standby and the fault tolerance of the force sharing without their associated drawbacks.

The fly-by-wire system used for this study is similar to the system developed under the Army HLH flight controls program. It was chosen because of its proven performance and conceptual simplicity. A further consideration was the availability of a proven design for demonstration of the integrated servo. Figure 3 shows a block diagram of a single stage of the actuator system. Each stage has an active electrical path and a model electrical path. Comparison monitoring between the paths is used to detect system faults. A comparison of valve driver signal to the displacement of the electrohydraulic valve (EHV) spool detects faults in the EHV. Comparison of the active and model driver amplifier outputs detects faults in the actuator servo loop. Dual actuator ram position transducers provide fault detection in the servo feedback loop. A self monitor circuit like that used in the HLH demonstrator detects faults in the single differential cylinder pressure transducer. Detection of a fault in any of the comparators puts the stage into bypass and disconnects the pressure feedback loop in the on-line stage. The on-line stage then becomes active. Subsequent failure of the second stage will result in that stage also being put into bypass. This system configuration, then, continues to operate in an undegraded fashion after a first system failure. A second failure results in degraded operation.

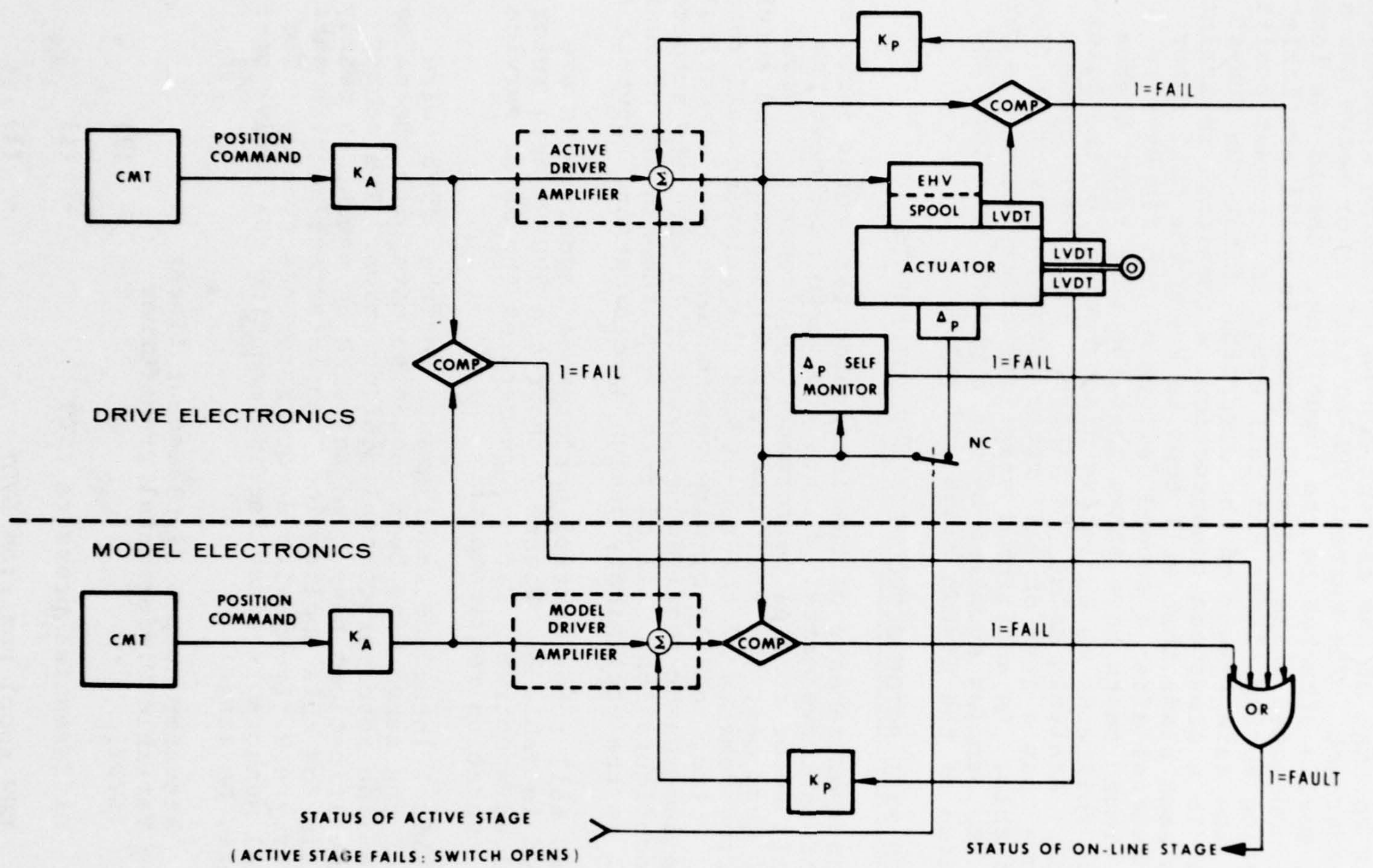


FIGURE 3. ACTUATOR CONTROL LOOP BLOCK DIAGRAM.

The operation of the tail rotor subsequent to a second failure is similar to that of the current YUH-60 following a mechanical control severance. The current YUH-60 tail rotor servo has a centering spring attached to the input link. Should the input become disconnected while hydraulic power is still available, the centering spring places the tail rotor in a preset position to permit the safe flight of the aircraft. Since the YUH-60 tail rotor is a crossbeam construction, a torsional restraint exists in each blade that will tend to bring the tail rotor pitch to neutral after a second failure of the fly-by-wire system. Ground tests have shown that the tail rotor blades are stable following an explosive disconnection of the pitch-change rod. Analysis using the Sikorsky tail rotor dynamic model shows that a loss of tail rotor pitch restraint in flight is also stable. An additional stability safety margin is provided by the damping supplied by the bypassed actuators and the friction of the piston rings and seals.

INTEGRATED TAIL ROTOR SERVO DESIGN REQUIREMENTS

The design requirements of the integrated tail rotor servo can be studied in three parts. First, the servo must meet the YUH-60 tail rotor control performance requirements. Second, the servo must meet the environmental, reliability, and survivability requirements of the YUH-60 and the existing tail rotor gearbox. Third, the fly-by-wire version must have electrical interface and sensor requirements compatible with the actuator control configuration. All of these requirements are presented in detail in the preliminary design specification, Appendix A.

The YUH-60 tail rotor control performance requirements are summarized in Table 2. Figure 4 shows the YUH-60 tail rotor control load spectrum. Table 3 summarizes the major service life and operation requirements.

The electrical interface requirements for the fly-by-wire version of the servo have been chosen to mate with the selected active-on-line actuator control configuration. The sensor output specifications have been selected to match, as nearly as possible for this application, the interface requirements for the Army HLH fly-by-wire demonstrator electronics. The electrical sensors required for implementing the active-on-line scheme are, on stage:

- Actuator output displacement Linear Variable Differential Transformer (LVDT) - (2)
- Differential pressure LVDT - (1)
- EHV spool position LVDT - (1)

TABLE 2. YUH-60 TAIL ROTOR CONTROL PERFORMANCE REQUIREMENTS SUMMARY*

. Output Stroke	3.55 inches
. Output Rate	125 percent per second at no load 88 percent per second at 1/2 stall load
. Rotor Speed Range Over Which Performance Requirements Must Be Met	80 - 125 percent N_R
. Maximum Control Load	2100 pounds (See Figure 4)
. Maximum Closed-Loop Time Constant	.020 second
. Open-Loop Frequency Response	20 Hz
. Mechanical Input Stroke	2.5 inches
. Servo Closed-Loop Stiffness	80,000 pounds per inch

*See Design Specification, Appendix A

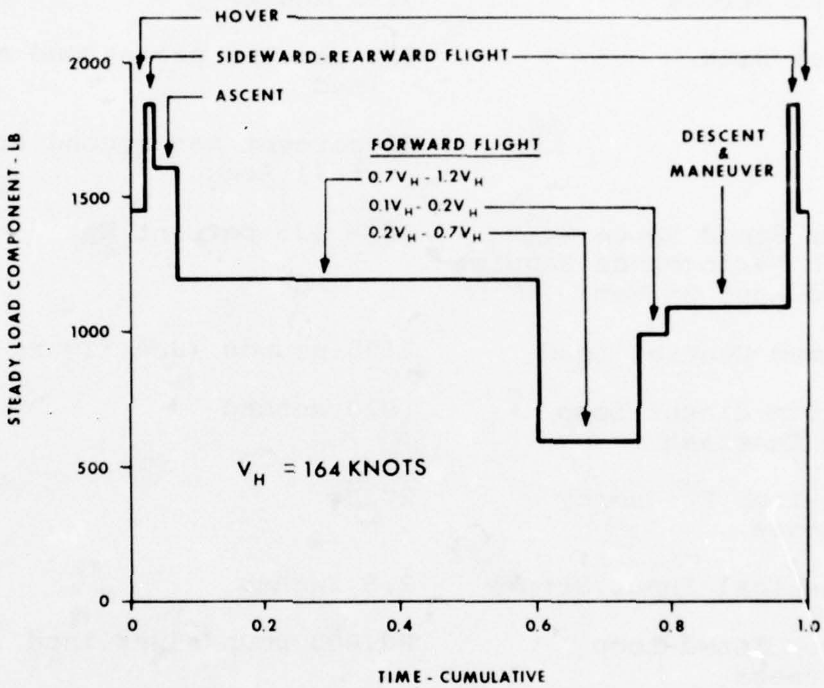


FIGURE 4. YUH-60 TAIL ROTOR CONTROL LOAD SPECTRUM.

TABLE 3. SERVICE LIFE AND OPERATION REQUIREMENTS SUMMARY*

. Gearbox Temperature	-65 to 275°F
. Acceleration	6 g's
. Survivability to Ballistic Threat	7.62mm @ 2550 feet per second
	12.7mm @ 1600 feet per second
. Aspect of Vulnerability	Lower hemisphere + 15 degrees
. Life	8000 hours
. Reliability	2500 hours MTBF
. Ground Test Provisions	Ground check with rotor stopped

*See Design Specification, Appendix A

INTEGRATED SERVO CONCEPT

The integrated fly-by-wire (FBW) tail rotor servo is a self-contained, dual module that fits in the envelope now occupied by the UTTAS mechanical input drive tail rotor servo. The servo module shown schematically in Figure 5 features FBW control, pressure-demand hydraulics and an active/passive failure detection with system switchover capability. Load, stroke and all other critical functional requirements of the existing UTTAS tail rotor servo are met or exceeded by the FBW integrated servo.

Hydraulic Power Supply System

The pressure demand concept that is used in this system is of prime importance because of its inherent low heat generation capability and simplicity. To provide the pressure control, a delta pressure (ΔP) regulator has been installed in each hydraulic system. Flow from the low pressure side of the reservoir is ported to a 1 gpm constant-flow gear pump. This output is then ported through a filter to both an electro-hydraulic servo valve (EHV) and to the ΔP regulating valve. The ΔP regulator will regulate supply pressure to a constant 300 psi above the higher metered pressure by means of a spool that is spring loaded and pressure biased. This is accomplished by restricting the amount of high-pressure fluid that can flow through the ΔP regulating valve to return. At a no-load condition with no actuator motion, the EHV maintains equal pressures on both sides of the actuator piston. With the 300 psi pressure bias, the pressure control loop will reach a steady state with 300 psi on each side of the actuator piston. The resulting supply pressure at this condition will be 600 psi.

When the actuator is reacting to a load, the EHV, on command, allows adequate pressure in the actuator so that the ΔP across the actuator piston can support that load. The ΔP regulator is biased by the higher of the two metered pressures from the EHV and, as a result, regulates the supply pressure to be 300 psi greater than the higher metered pressure level. Since the higher metered pressure must react the load plus the lower metered pressure, the lower metered pressure will be a constant 300 psi. The pressure relationships are shown in Equations 1 through 5.

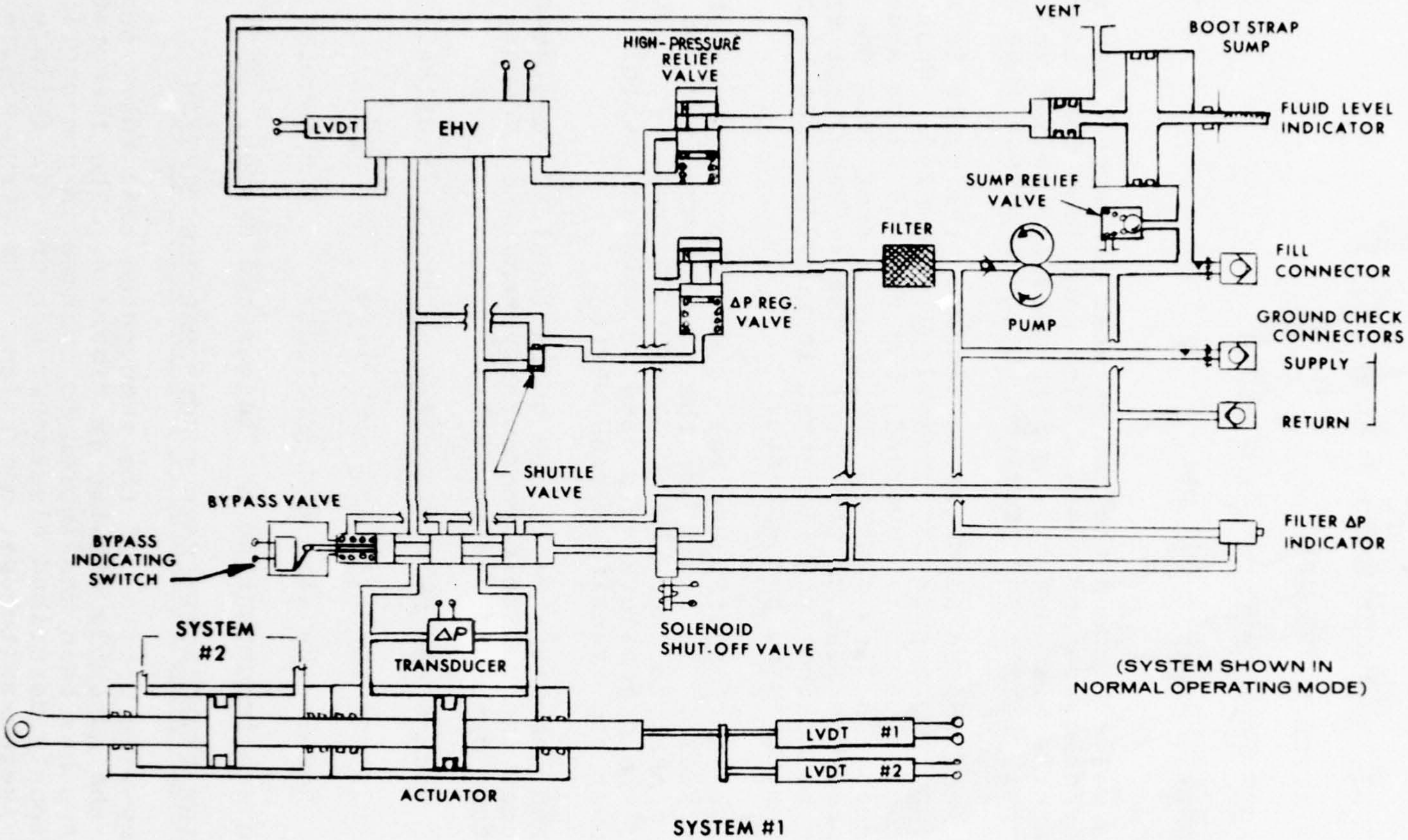


FIGURE 5. HYDRAULIC SCHEMATIC - INTEGRATED SERVO POWER MODULE.

$$P_{SUPPLY} = P_{HIGH\ METER} + 300\ psi \quad (1)$$

$$P_{SUPPLY} = P_{HIGH\ METER} + P_{LOW\ METER} \quad (2)$$

$$P_{LOW\ METER} = 300\ psi \quad (3)$$

$$P_{LOAD} = P_{HIGH\ METER} - P_{LOW\ METER} \quad (4)$$

$$P_{SUPPLY} = P_{LOAD} + 600\ psi \quad (5)$$

A shuttle valve between the two metered pressure lines selects the higher pressure and opens a flow path from that line to the ΔP regulator's bias cavity. A high-pressure relief valve, set for 3000 psi, limits any pressure build-up beyond that limit.

When the load on the actuator is reduced, the cycle is reversed, and the supply pressure is automatically lowered. When the load on the actuator is reversed, the shuttle valve shuttles and switches the flow path to the ΔP regulator from one metered pressure line to the other. The ΔP regulator then continues to monitor the line that is providing the higher of the two pressures to the actuator.

The ΔP regulator control has been used extensively in propeller control systems. In addition, the concept was used and thoroughly analyzed for the XC142 VTOL control. For that aircraft, the propellers were used to maintain vehicle altitude during hover and transition maneuvering.

It has been demonstrated by the operational ΔP-regulated systems that the variable pressure system, when compared to the constant pressure system, will:

1. Reduce the heat generated by the hydraulics.

2. Extend the seal and pump life.

3. Reduce the size and complexity of the pumping system.

All three are important to the integrated system.

FLY-BY-WIRE INTEGRATED SERVO FUNCTIONAL DESCRIPTION

The fly-by-wire version of the integrated tail rotor servo is shown in the assembly drawing in Figure 6. The integrated tail rotor servo has been configured to operate in conjunction with the previously described electronic network for failure detection and system-switchover operation. The servo module has

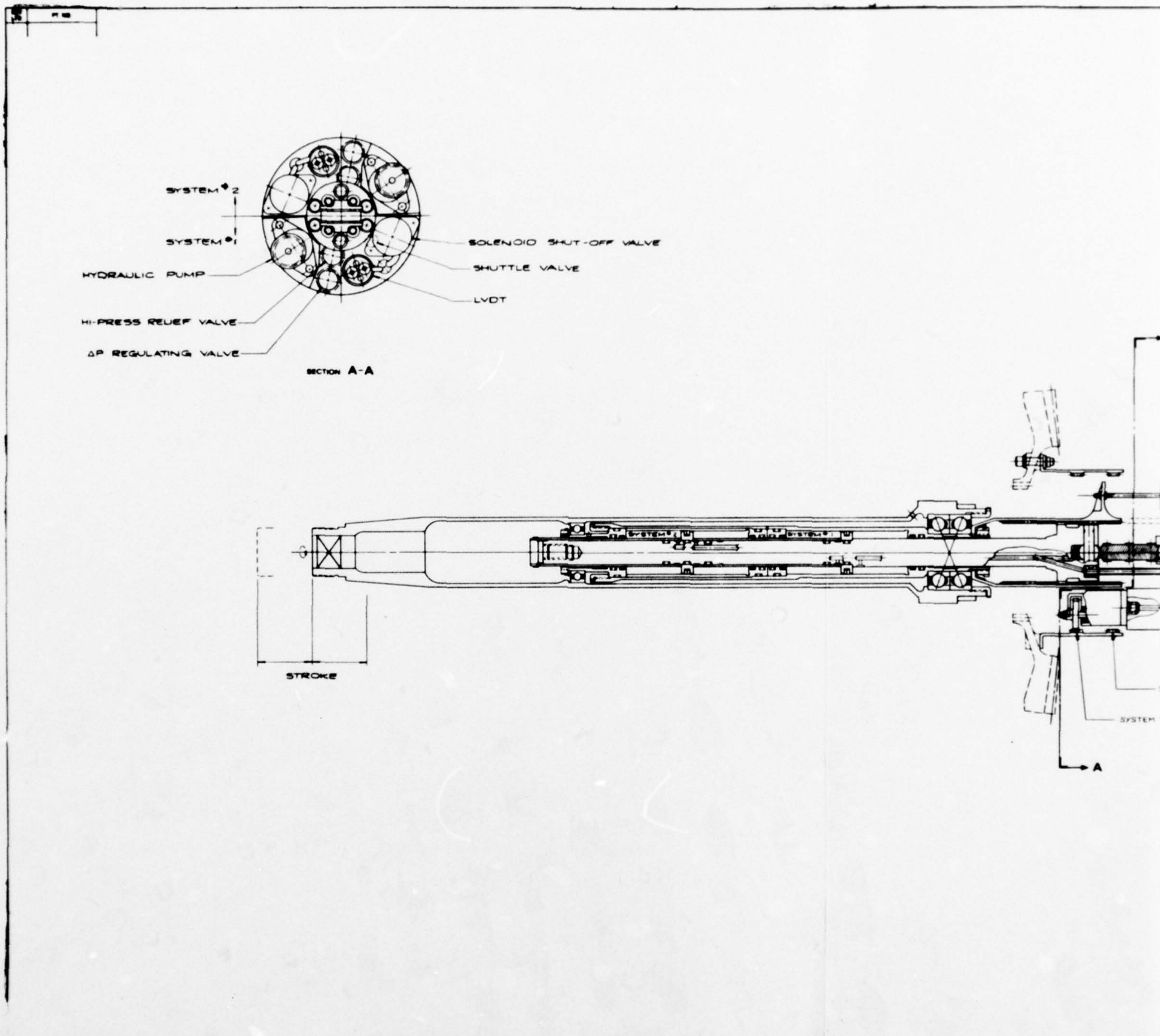
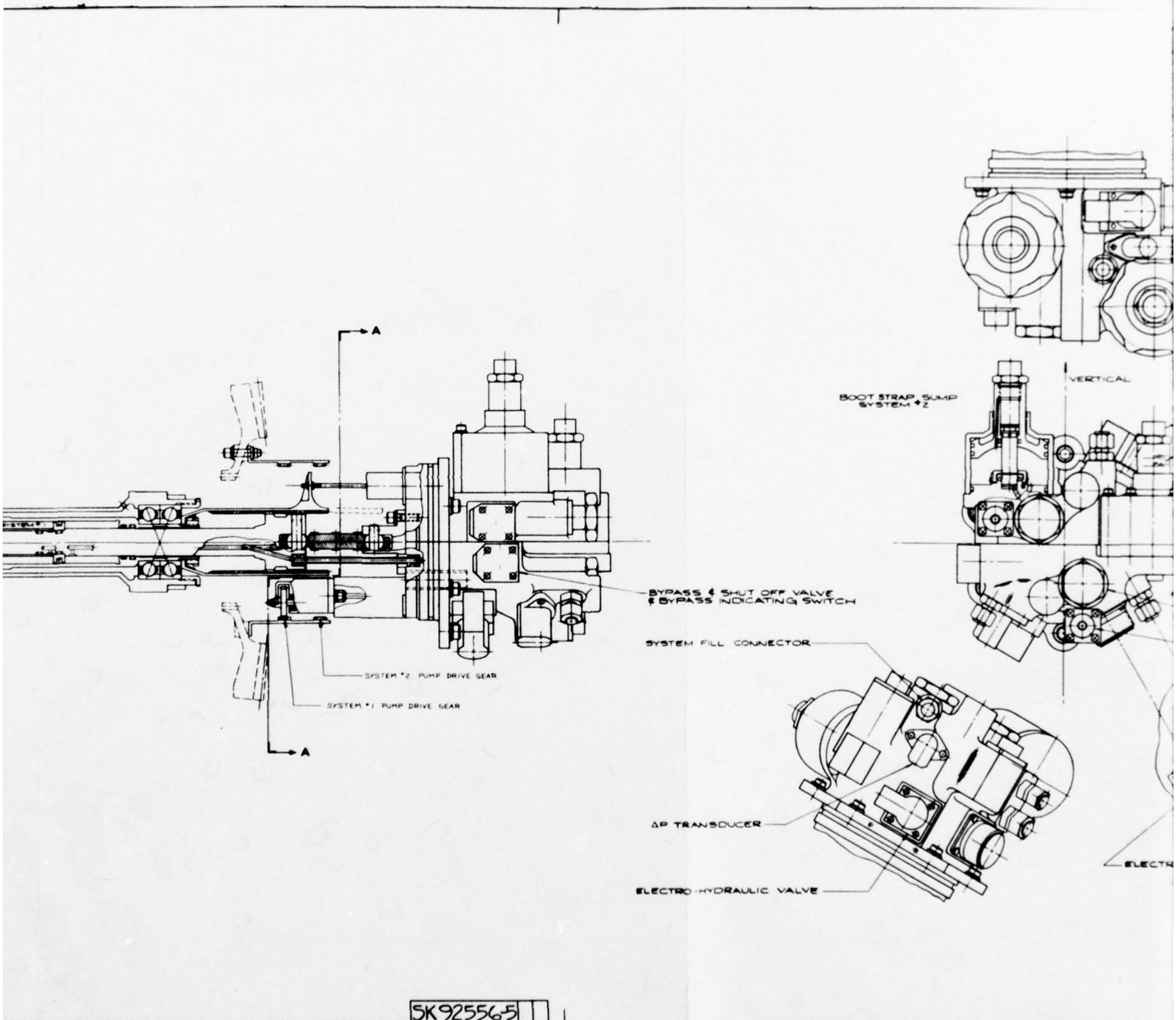


FIGURE 6. FLY-BY-WIRE INTEGRATED TAIL ROTOR SERVO ASSEMBLY.


A
A
VERTICAL
BOOT STRAP SUMP
SYSTEM #2
BYPASS & SHUT OFF VALVE
& BYPASS INDICATING SWITCH
SYSTEM FILL CONNECTOR
SYSTEM #2 PUMP DRIVE GEAR
SYSTEM #1 PUMP DRIVE GEAR
ΔP TRANSDUCER
ELECTRO-HYDRAULIC VALVE
SK92556-5

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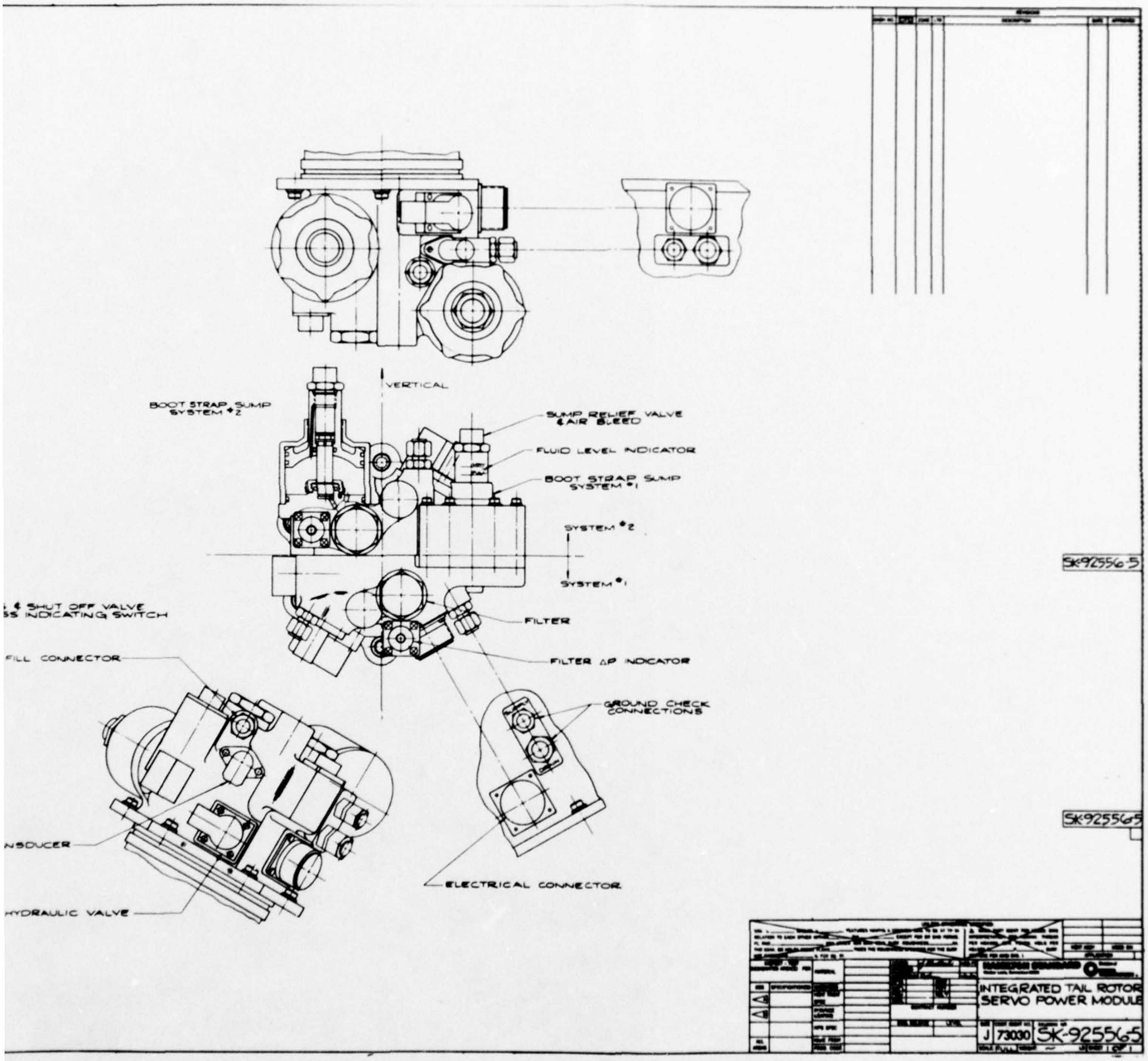

VERTICAL
BOOT STRAP SUMP SYSTEM #2
SUMP RELIEF VALVE & AIR BLEED
FLUID LEVEL INDICATOR
BOOT STRAP SUMP SYSTEM #1
SYSTEM #2
SYSTEM #1
& SHUT OFF VALVE
SS INDICATING SWITCH
FILL CONNECTOR
FILTER
FILTER ΔP INDICATOR
GROUND CHECK CONNECTIONS
NSDUCER
ELECTRICAL CONNECTOR
HYDRAULIC VALVE
SK-92556-5
SK-92556-5
INTEGRATED TAIL ROTOR SERVO POWER MODULE
J 73030 SK-92556-5

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built-in electrical sensors in three locations on each of two systems for the failure detection and switchover capability. Each system also has a pressure transducer that senses the pressure differences across their respective actuators' piston heads. The signal from these transducers acts to maintain the two systems' "active," "on-line" roles. Both systems in the module are identical in content and functional capability. Each system can provide the maximum power that is required to hold or reposition the rotor blade.

The power to drive the system's two hydraulic pumps is taken from the tail rotor gear train. A ring gear is attached to the drive train that in turn transfers power to two 1-gpm constant flow gear pumps. Each pump provides the pressure and flow for independent and isolated hydraulic systems. Independent housings are used for each system to prevent crack propagation in the event of a structural failure. Dual dynamic seals without vents are used to reduce complexity.

Both hydraulic systems can be serviced externally and have visual indicators to allow the detection of a low fluid condition or an abnormal delta pressure across the system's filter. For protection, all hydraulic lines and electrical wiring are routed internally. The servo module is installed and removed as a complete package. It can be functionally tested on the bench as a unit for troubleshooting or certification.

A bootstrap reservoir is incorporated in each hydraulic system. The reservoirs have been placed at the high point in the module to collect any air that is in the systems. The bootstrap operation is obtained by porting high-pressure fluid to a small diameter piston and return fluid to an opposing, large diameter piston. The area ratios are 45:1 so that the return pressure will always be 1/45 of the supply pressure. An advantage of the bootstrap reservoir is that no springs are used, thereby reducing system size and weight.

FUNCTIONAL DESCRIPTION OF THE MECHANICAL INPUT TO THE INTEGRATED SERVO

The mechanically operated, integrated tail rotor servo is also a self-contained module that has redundant hydraulic channels. The mechanical system, like the fly-by-wire system, uses a pressure-demand delta-pressure regulator. However, with the mechanical concept, both hydraulic systems are on line together. The servo module is shown schematically in Figure 7 and in an assembly cross section in Figure 8.

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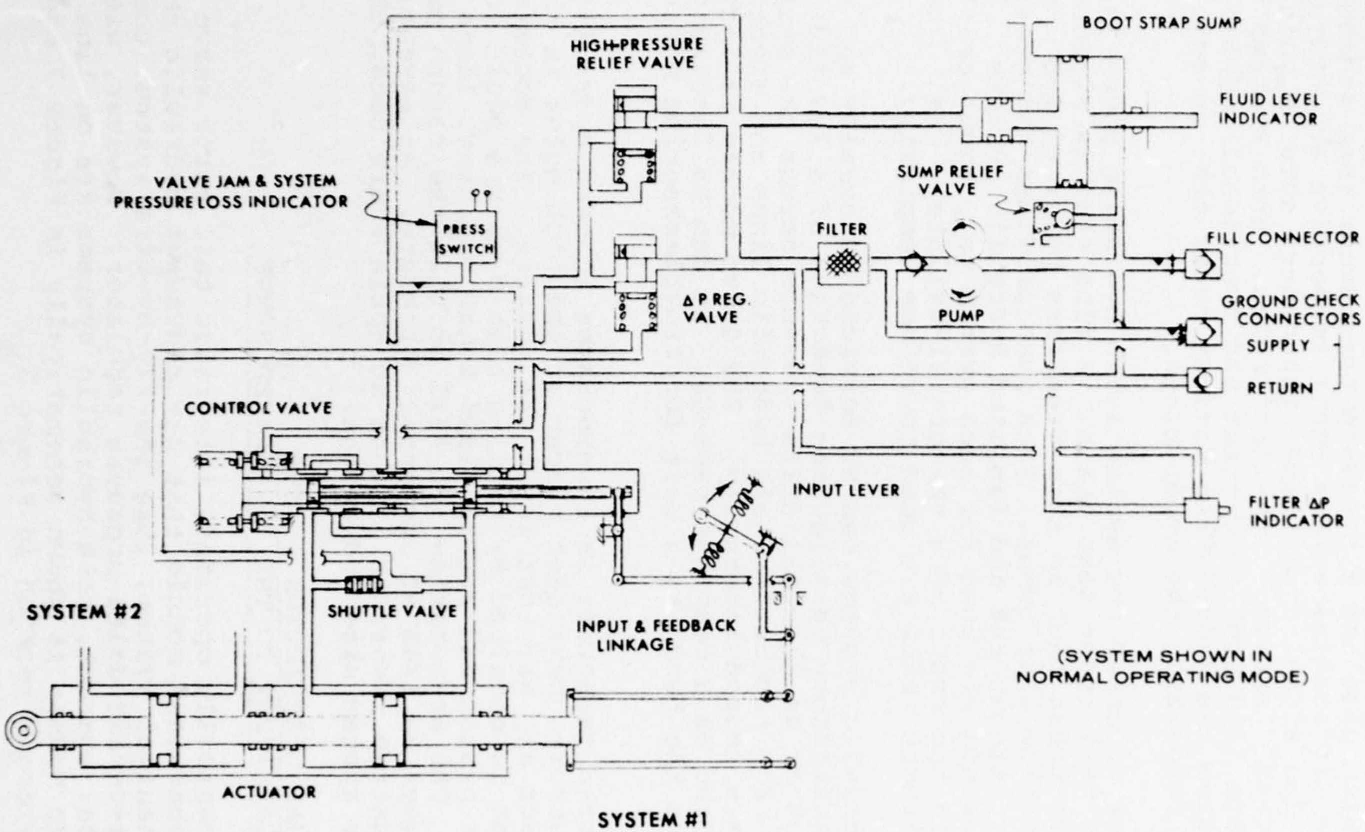


FIGURE 7. HYDRAULIC SCHEMATIC - INTEGRATED SERVO POWER MODULE - MECHANICAL INPUT.

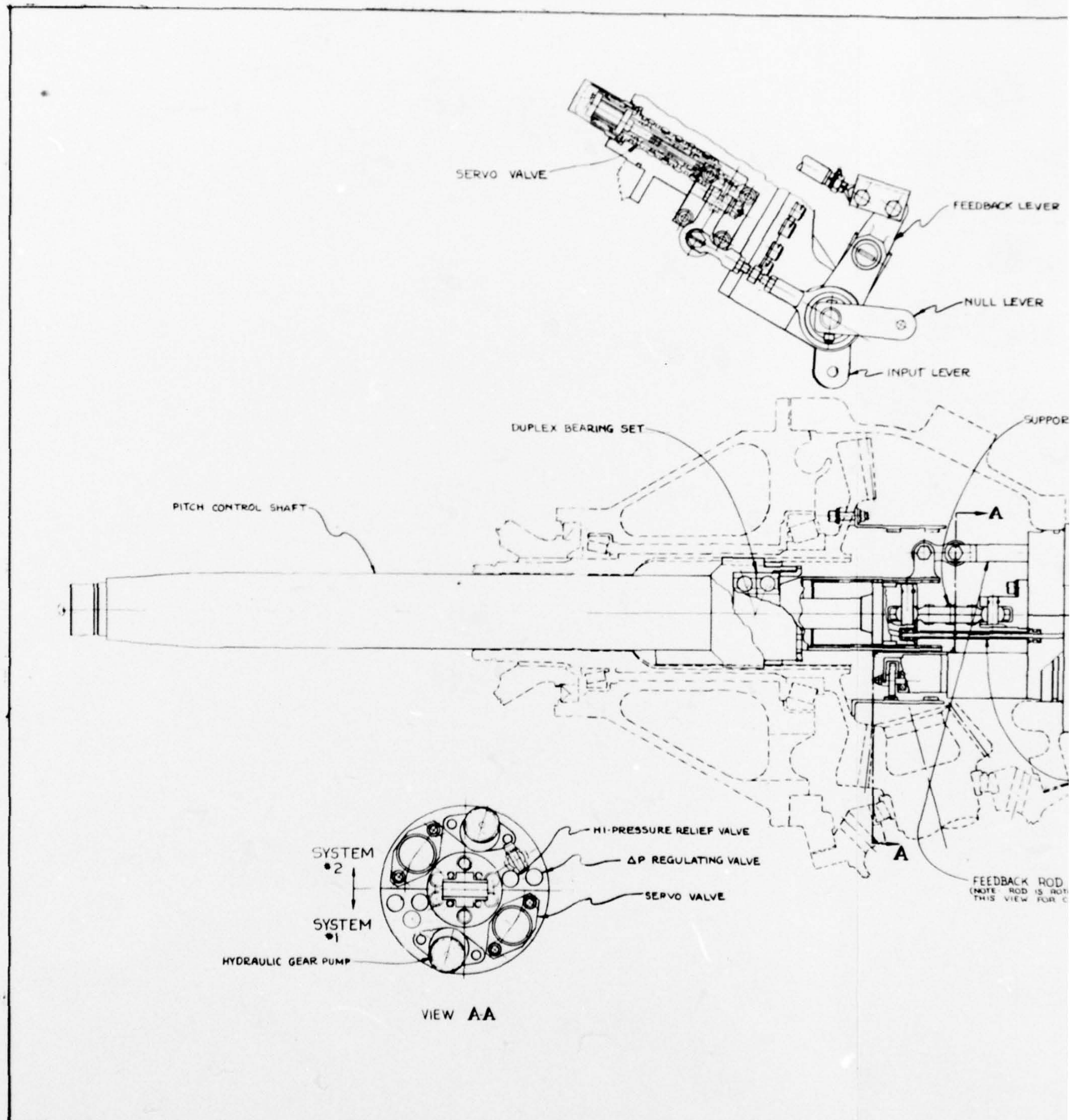
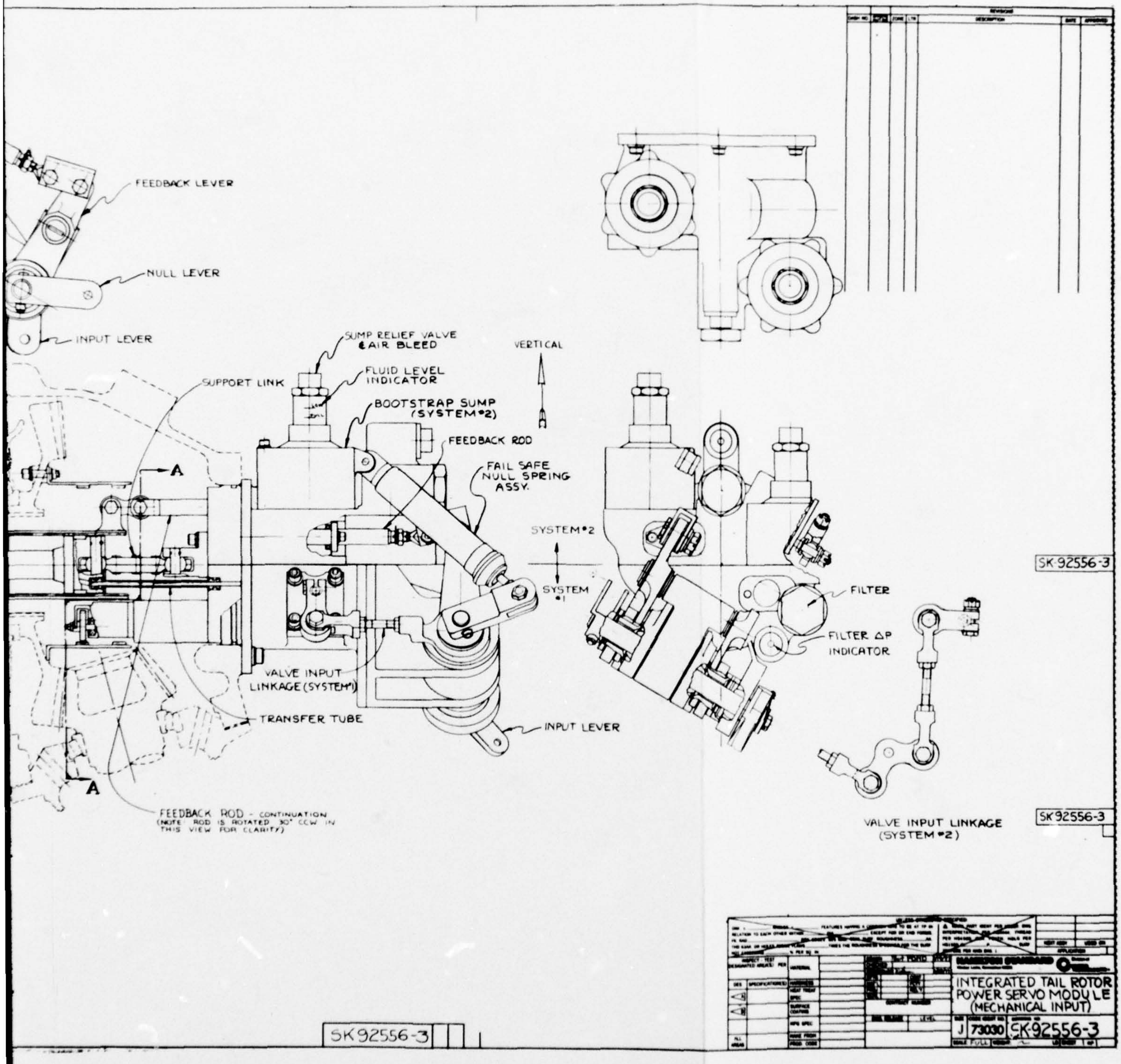


FIGURE 8. MECHANICAL INPUT INTEGRATED TAIL ROTOR SERVO ASSEMBLY.


FEEDBACK LEVER
NULL LEVER
INPUT LEVER
SUMP RELIEF VALVE
& AIR BLEED
FLUID LEVEL
INDICATOR
SUPPORT LINK
BOOTSTRAP SUMP
(SYSTEM #2)
VERTICAL
FEEDBACK ROD
A
FAIL SAFE
NULL SPRING
ASSY.
SYSTEM #2
SYSTEM #1
FILTER
FILTER ΔP
INDICATOR
VALVE INPUT
LINKAGE (SYSTEM #1)
TRANSFER TUBE
INPUT LEVER
A
FEEDBACK ROD - CONTINUATION
(NOTE: ROD IS ROTATED 30° CCW IN THIS VIEW FOR CLARITY)
VALVE INPUT LINKAGE
(SYSTEM #2)
SK 92556-3
SK 92556-3
SK 92556-3
INTEGRATED TAIL ROTOR
POWER SERVO MODULE
(MECHANICAL INPUT)
J 73030 SK-92556-3
SCALE FULL

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Either system is capable of supplying full power; however, with both systems operative, there will be load sharing. It is recognized that, when two hydraulic systems operate simultaneously and are coupled to drive a common load, it is important that the control valve nulls be carefully matched to minimize the region over which the valves can establish opposing actuator pressures.

The use of the delta-pressure regulator tends to reduce the valve pressure sensitivity around no-load and, therefore, makes matching system pressures at this point less of a problem than with a system that operates with a constant regulated supply pressure. Figure 9 shows the pressure gain curves for both a constant pressure system and the variable pressure regulation system.

To minimize control valve mismatch effects, two adjustment points have been incorporated into the actuator feedback linkage network. This permits both of the control valve nulls to be adjusted at both ends of the actuator stroke. By using position and rate adjustments, the nulls of both valves can be matched to within $\pm .0005$ inch at both ends of the actuator stroke. When nulled to these limits, the no-load steady state system pressure will not be more than 200 psi above the 600 psi that could be achieved with a perfect match. Figure 10 shows a typical system pressure increase, approximately 100 psi at no-load for combined system operation, where nulls are mismatched by .0005 inch. This curve shows that the no-load pump pressure around null increases as a function of mismatch and, therefore, should be carefully controlled. It also shows that, because each system is designed to carry the full load, perfect load sharing in moderate load conditions is not required. However, a load sharing condition with delta pressure regulation keeps the pressure level of both systems down, which results in less heat generation and uniform heat disipation in both systems.

The construction of the components of the mechanical input servo module with the exception of the EHV's and LVDT's for electrical input and feedback is similar to the FBW module.

The pumps, reservoirs, ΔP regulator, high-pressure relief valves, filters, fill connectors, ground checkpoints and filter ΔP indicators are identical. The delta-pressure regulator's function and pressure settings are also identical.

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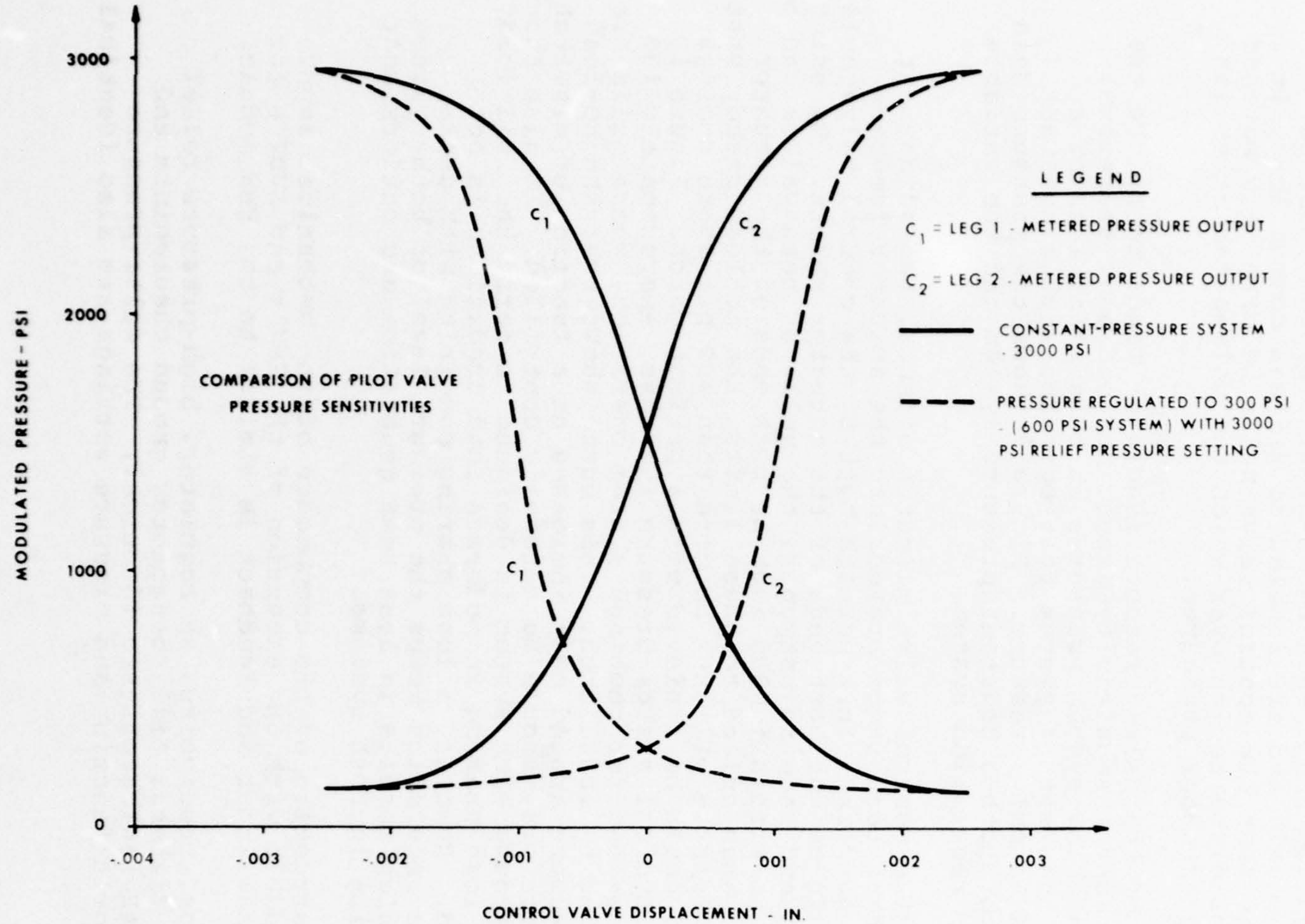


FIGURE 9. PRESSURE GAIN FOR CONSTANT-PRESSURE AND PRESSURE-REGULATED SYSTEMS.

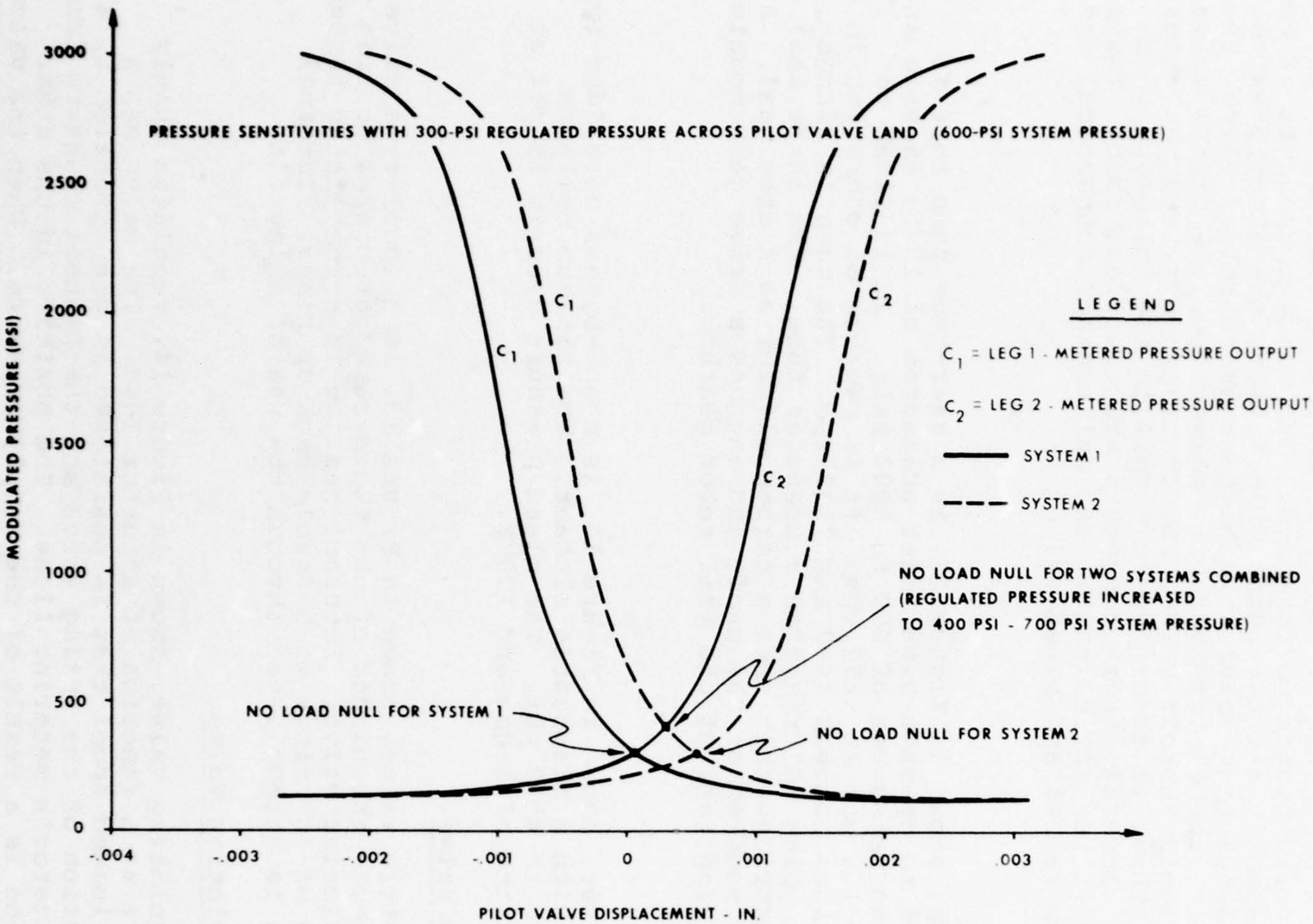


FIGURE 10. EFFECTS OF VALVE MISMATCH ON SYSTEM PRESSURE AND FORCE FIGHT.

FLY-BY-WIRE INTEGRATED SERVO DETAILED COMPONENT DESCRIPTION

The fly-by-wire integrated servo components, shown in the hydraulic schematic of Figure 5, have been designed to provide the required system performance. The major components of the servo assembly are the pumps, the filter, the shuttle valve, the ΔP regulating valve, the high-pressure relief valve, the reservoir, the electrohydraulic servovalve, the bypass valve, the solenoid shutoff valve, the ΔP transducer, and the actuator. Each of these is described in detail in the following paragraphs. Several minor components are also described. These are the filter ΔP indicator, the maintenance connectors, and the sump relief and bleed valve.

Pump

The pump, shown in Figure 11, is a gear-type pump that is designed to operate with inlet pressures of 12 to 65 psig and discharge pressures of 600 to 3000 psig. It is sized to produce 1.0 gpm at 5871 rpm. It is capable of operating in a speed range between 4697 and 7338 rpm. The pump is flange-mounted using "O" rings on a transfer tube. The shaft seal is a cartridge that uses a carbon element as a face seal. A gear is mounted on the shaft and engages a drive gear mounted on the ring gear of the tail rotor gearbox.

Filter

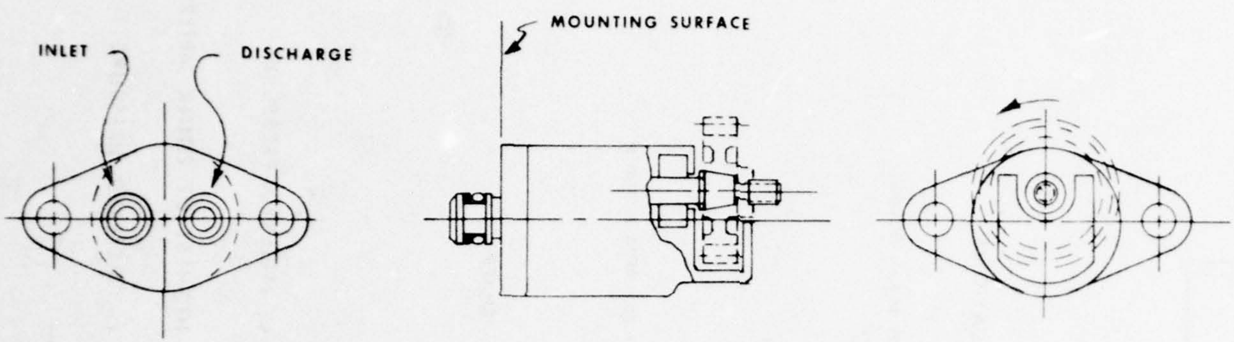
The filter, shown in Figure 12, is a non-bypass cartridge-type filter with a disposable element. The minimum collapse pressure is 4500 psi. The clean pressure drop is 15 psi at a flow rate of 1 gpm and 100°F.

Shuttle Valve

The shuttle valve, shown in Figure 13, is a spool-type valve and selects the higher of the two metered pressures to bias the ΔP regulating valve. External sealing is accomplished through the use of "O" rings with double back-up rings. Internal sealing is accomplished through the use of a lap fit.

ΔP Regulating Valve

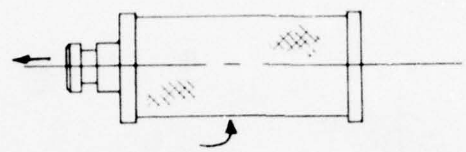
The regulating valve, shown in Figure 14, regulates supply pressure as a function of actuator load. The valve has a spring-loaded spool that is positioned in one direction by a combination of the spring force and the highest pressure from the actuator's metering lines. The position in the other direction is a result of the supply pressure. When the valve is in an open position, the supply pressure is ported to return via the open center of the valve. Supply pressure also flows



PUMP

FLUID:	MIL-H-5606 OR MIL-H-83282
TEMP:	-65°F TO 275°F
RPM:	5871 @ 100% 4697 RPM MIN 7338 RPM MAX
CAPACITY:	1GPM @ 4697 RPM
PRESSURE:	
INLET:	12 PSIG → 65 PSIG
DISCHARGE:	600 PSIG → 3000 PSIG
ALTITUDE:	S. L. TO 20,000 FT

FIGURE 11. HYDRAULIC PUMP.



NONBYPASS FILTER SPECIFICATIONS

DISPOSABLE TYPE:

FLUID: MIL-H-5606 OR MIL-H-83282

TEMP: -65°F TO 275°F

FILTRATION DEGREE:

5u NOMINAL

15u ABSOLUTE

MIN COLLAPSE PRESSURE:

4500 PSI

PRESSURE DROP:

CLEAN 15 PSI @ 1GPM & 100°F

FIGURE 12. FILTER.

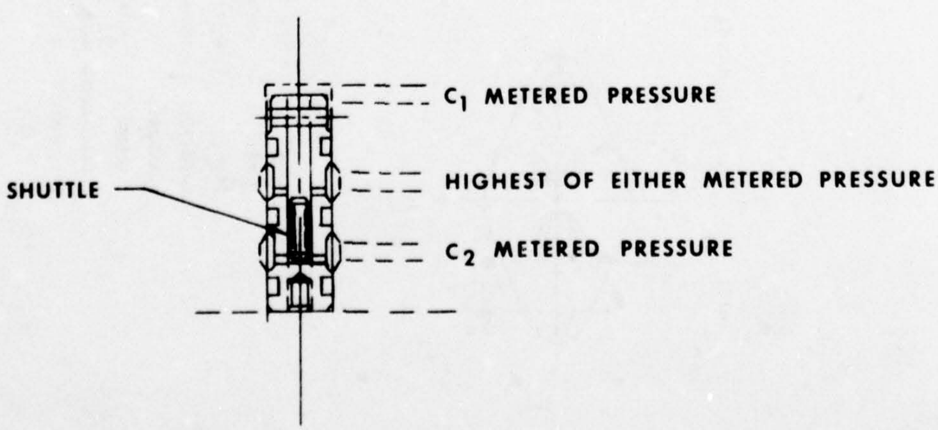
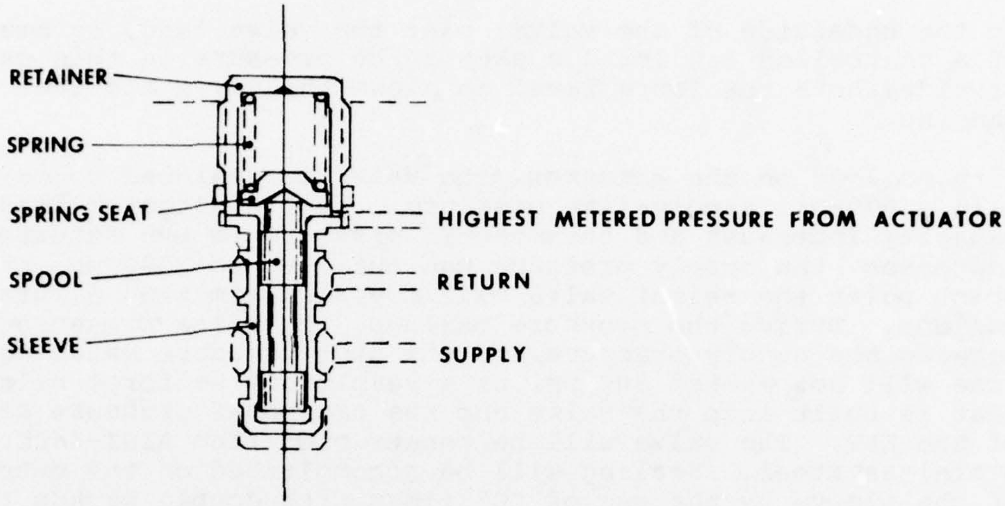


FIGURE 13. SHUTTLE VALVE.



VALVE SPECIFICATIONS

FLUID:	MIL-H-5606 OR MIL-H-83282
TEMP:	−65°F TO 275°F
CAPACITY:	SEE CURVE
PRESSURE:	
RETURN:	12 PSIG TO 65 PSIG
SUPPLY:	600 PSIG TO 3000 PSIG
METERED:	300 PSIG TO 3000 PSIG

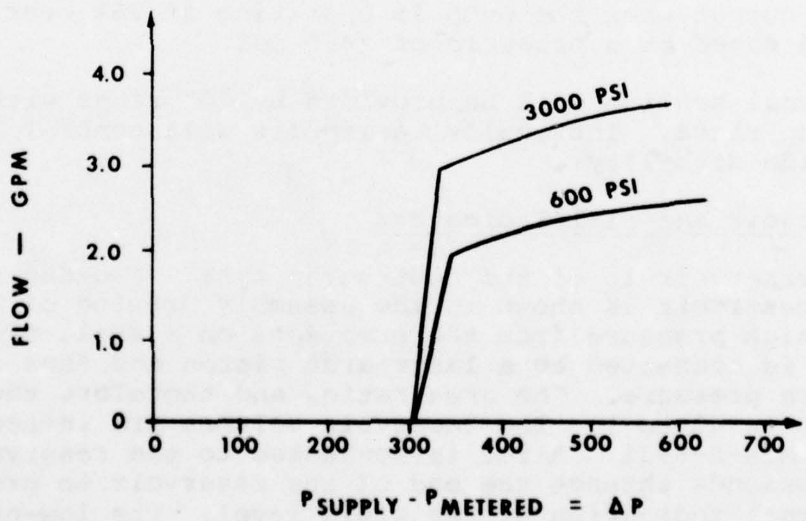


FIGURE 14. ΔP REGULATING VALVE.

to the underside of the valve, past the valve land, by means of a controlled lap leakage path. The pressure in this cavity provides both the force level to close the valve and the damping.

With no load on the actuator, the valve is designed to maintain a 600-psi supply-line pressure. As the actuator load capacity increases and the metered pressure to the actuator increases, the supply pressure can build up to 3000 psi at which point the relief valve will operate, limiting a further buildup. During the pressure buildup, the delta pressure between the supply pressure and the high-pressure metering line will not exceed 300 psi as a result of the force balance that is built into the valve and the crossover pressure setting of the EHV. The valve will be constructed from AISI-440C stainless steel. Sealing will be accomplished on the outside of the sleeve by the use of "O" rings with double backup rings. The lap fit on the inside of the sleeve will control leakage and the stability of the valve.

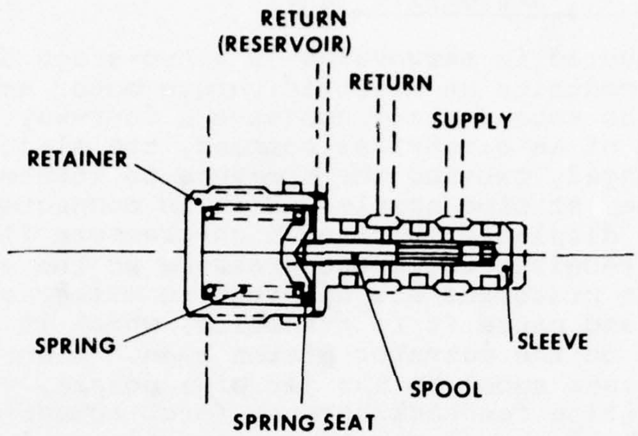
High-Pressure Relief Valve

The high-pressure relief valve, shown in Figure 15, is incorporated to prevent overpressurization of the system due to a maintenance error and also as a limit for the ΔP regulator. The valve primarily consists of a spring-loaded spool that will react when the pressure exceeds 3000 psi. Supply pressure is ported to an open center in the spool and, by a controlled lap, leaked to the end of the spool to provide the shuttling force and the damping. The valve is sized to pass the total pump output when the pump is operating at 25% over its normal rated speed at a pressure of 3450 psi.

External sealing will be provided by "O" rings with double backup rings. Internally, a lap fit will control leakage and provide stability.

Reservoir and Fill Indicator

The reservoir is of the boot-strap type. A cross section of the reservoir is shown in the assembly drawing of Figure 6. The high pressure from the pump acts on a small-area piston that is connected to a large-area piston and thus creates return pressure. The area ratio, and therefore the pressure ratio is 45 to 1. The reservoir volumes are in accordance with MIL-R-8931. A rod is connected to the reservoir piston and extends through the end of the reservoir to provide an external indication of the fluid level. The low-pressure relief valve is incorporated in the piston rod level indicator.



VALVE SPECIFICATIONS

FLUID:	MIL-H-5606 OR MIL-H-83282
TEMP:	-65°F TO 275°F
CAPACITY:	SEE CURVE
PRESSURE:	SEE CURVE

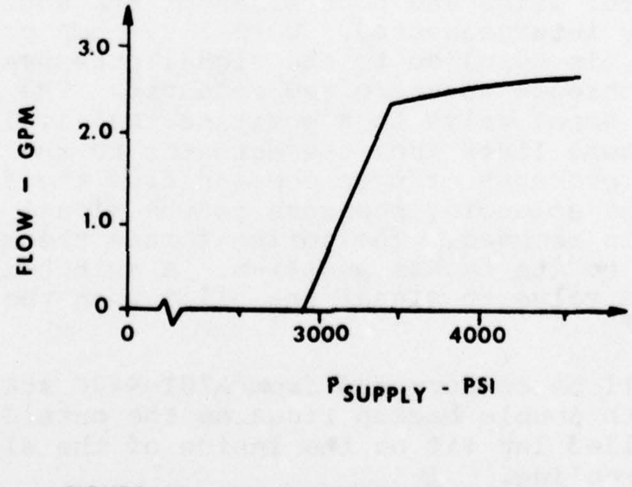


FIGURE 15. HIGH-PRESSURE RELIEF VALVE.

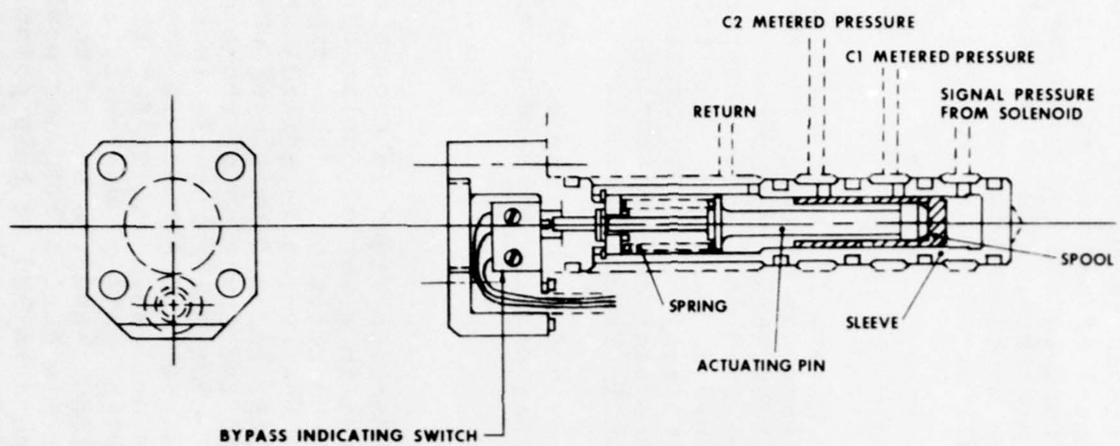
Electrohydraulic Servovalve (EHV)

The electrohydraulic servovalve is a two-stage device. The first stage contains an electric torque motor and jet pipe valve, and the second stage contains a four-way spool valve. Upon receipt of an electrical command, the electromagnetic field is changed, causing the armature to rotate on its flexure. The jet pipe nozzle, which is connected to the armature, is displaced, porting high-pressure fluid to one side of the receiver while the pressure at the other side drops. These pressures are directed to either side of the spool valve and cause it to translate, which in turn changes the pressure on the actuator piston head. A spring connects the second-stage spool to the jet pipe nozzle, providing internal position feedback through force summation. Therefore, the pressure and the flow rate are functions of the electrical input command. The torque motor is dry and is sealed from the fluid portion of the valve by a flexure tube. The mounting face is sealed through the use of "O" rings. The outside of the sleeve has "O" rings with double backup rings to effect sealing. A lap fit between the spool and sleeve controls internal leakage. The four-way spool valve is constructed of AISI-440C stainless steel. An LVDT is connected to the second-stage spool to provide a monitoring function for the electrical network.

Bypass Valve

The bypass valve, shown in Figure 16, is provided to prevent drag or hydraulic lock of the actuator in the event that there is a failure somewhere in the system. The bypass valve is basically a spool valve that is spring-loaded to a bypass position. When in bypass, both of the electrohydraulic servovalve's control lines and both sides of the actuator are hydraulically interconnected. Normally, pump pressure, 600 psig minimum, is supplied to the signal pressure end of the spool valve through an energized solenoid. The pump pressure shuttles the spool valve to a position that isolates the metered pressure lines from the actuator to the EHV. Upon loss of pump pressure or upon command from the failure logic network to the solenoid, pressure to the signal end of the spool valve is removed. The spring forces the spool valve to shuttle back to its bypass position. A switch is incorporated in the bypass valve to signal the pilot when the valve is in bypass.

The valve will be constructed from AISI-440C stainless steel. "O" rings with double backup rings on the outside of the sleeve and a controlled lap fit on the inside of the sleeve will provide the sealing.



VALVE SPECIFICATIONS

FLUID:	MIL-H-5606 OR MIL-H-83282
TEMP:	-65°F TO 275°F
PRESSURE:	
RETURN:	12 PSIG TO 65 PSIG
METERED:	RETURN PRESSURE TO 3000 PSIG
SIGNAL:	RETURN PRESSURE TO 3000 PSIG
MIN PRESSURE TO OPERATE VALVE:	300 PSI

FIGURE 16. BYPASS VALVE.

Solenoid Shutoff Valve

The solenoid shutoff valve is a three-way spool valve operated by an electrical command. The function of this valve is to supply pressure to the bypass valve for normal operation. The spool is connected to the core of the shuttle valve and is also referenced to a spring. When current is applied to the solenoid, the spool is positioned to supply pump pressure to the bypass valve. Upon removal of the current, the spring shuttles the spool, which connects the bypass valve to the return and blocks off pump pressure. The valve is flange-mounted. The outside of the spool incorporates "O" rings with double backup rings for sealing. Internal leakage is controlled by a lap fit.

ΔP Transducer

The ΔP transducer, shown in Figure 17, will sense the difference in pressure across an actuator piston. The transducer will be a linear-voltage-differential-transformer (LVDT) with dual coils. The LVDT is attached to a spring-centered piston that senses a metered pressure at each end. Excitation will be 115 VDC, 400 Hz. The two coils provide complementary outputs that are used for feedback and monitoring. These output curves are also shown in Figure 17.

External sealing will be provided by the use of "O" rings with double backup rings. Internal sealing will be provided by a controlled lap fit.

Actuator

The actuator, shown in the section view in Figure 6, is a tandem device that is mounted in a set of duplex bearings and a support bearing to allow the rotation of the output shaft. The actuator is attached to the hydraulic control unit through a redundant link that contains rod end bearings, which allow for the eccentricity between the mounting of the hydraulic unit and the output shaft. Hydraulic pressure is supplied to the actuator through transfer tubes that are connected to a central rod that contains drilled passages for fluid porting. Rotation of the actuator cylinder is prevented by a set of splines attached to the cylinder and the end of the interconnecting link. Each system's dual LVDT's for position feedback and monitoring are also attached at this point. All the actuator static seals are "O" rings with double backup rings. No redundancy is provided for static seals. The dynamic seals are redundant but are not vented. The seals choosen for this application are a unidirection seal exposed to the high internal pressure and a bidirectional seal used externally. The piston head seals are filled teflon piston rings. The structural parts of the actuator are designed with large

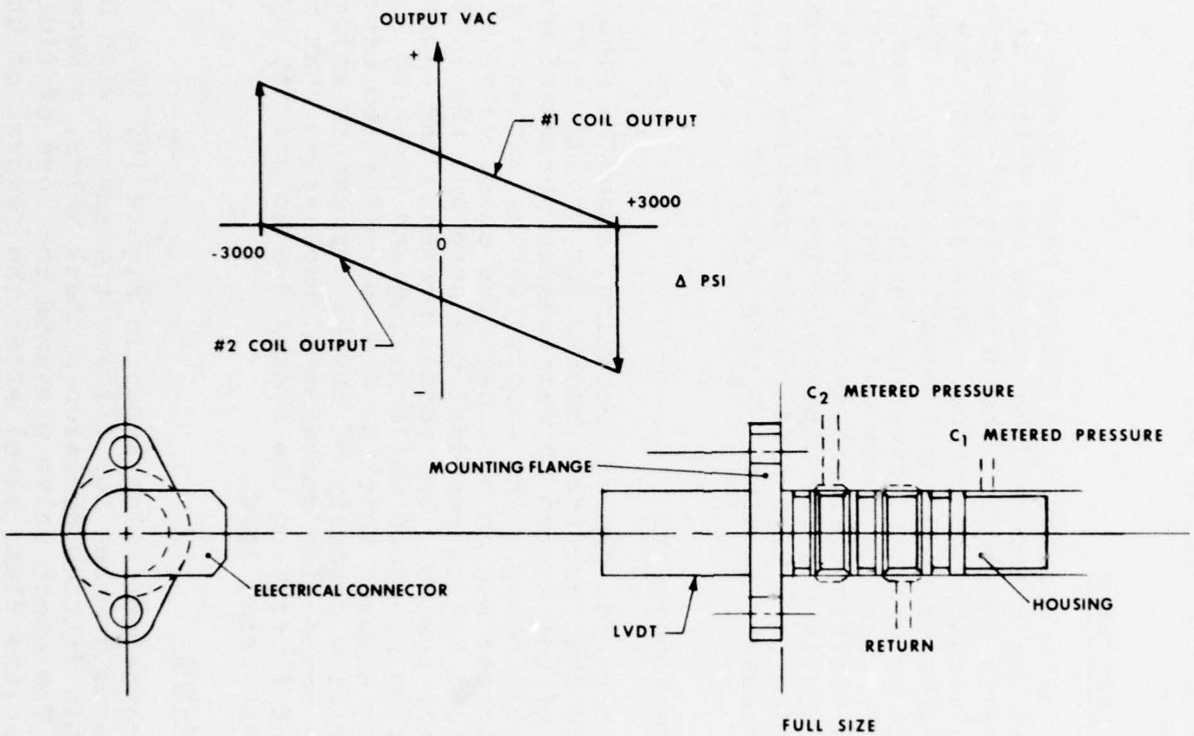


FIGURE 17. ΔP TRANSDUCER.

margins of safety due to the lack of redundancy. The retaining nuts will be safetied by the use of deformed retainers. The output shaft and the duplex bearing set are the same as the ones currently used in the YUH-60. The duplex bearing set is lubricated by the gearbox oil, while the support bearing is grease packed.

Filter ΔP Indicator

The filter ΔP indicator is a device that extends a red warning button when the pressure drop across the filter in the fluid system exceeds 150 psid. The principle of magnetic repulsion is used to actuate the button. Once actuated, the red warning button remains tripped until manually reset. A thermal lockout is provided to prevent actuation during "cold starts," below $80^{\circ}F \pm 20^{\circ}F$, when the increased viscosity of the fluid can cause high differential pressures across the filter element. Also included is a surge control device that prevents false actuation due to a high differential pressure caused by a flow surge or pressure impulse. A time delay of .5 second will be utilized.

Maintenance Connectors

The connectors for ground operation, shown in Figure 18, are full unions that provide a hookup for ground carts for the operation of the system by maintenance personnel while the rotor is stationary. The supply fitting contains a check valve, a screen and an orifice. The check valve prevents the loss of fluid due to residual pressure and the ingestion of air into the system. The screen prevents the entrance of contamination produced while making and breaking connections. The orifice ensures that the flow permitted to enter does not exceed the flow capacity of the high-pressure relief valve. The return connection contains a check valve that prohibits the loss of fluid from the system due to gravity by incorporating a light spring load.

Fill Connector

The fill connector, also shown in Figure 18, is a full union that provides a means for filling the system with hydraulic fluid. This fitting contains a check valve, a screen and an orifice. The check valve prevents the loss of fluid in order to maintain the fluid level after the removal of the device for filling. The screen is used to trap any large particles that might be introduced to the system during filling. The orifice ensures that the flow allowed to enter through the fill connector does not exceed the flow capacity of the sump relief valve.

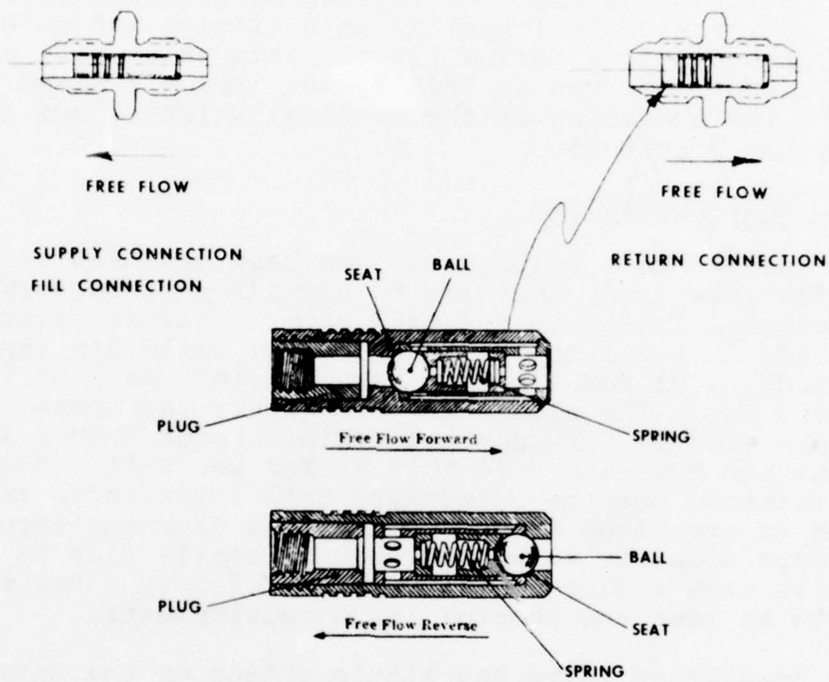


FIGURE 18. MAINTENANCE CONNECTORS.

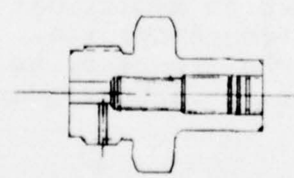


FIGURE 19. SUMP RELIEF VALVE AND AIR BLEED.

Sump Relief Valve and Air Bleed

The sump relief valve, shown in Figure 19, is incorporated to prevent overpressurization of the return side of the system due to malfunction, improper filling or ground operation error. This valve is installed in a fitting and references return pressure to a spring force. This valve will pass the full flow of the pump at 120% speed. The air bleed function requires the loosening of the fitting, which allows the air to pass by the port seal.

DYNAMIC CHARACTERISTICS

The integrated tail rotor servo has been designed to provide sufficient frequency response to provide satisfactory SAS and pilot-control inputs to the tail rotor. Normal pilot-control inputs are in the 1-Hz frequency range, while SAS inputs usually range from .3 Hz for aircraft response to over 2 Hz in turbulent air. The closed-loop frequency responses of the SAS actuators used in Sikorsky helicopters range from a low of 3 Hz for the S-58 and S-56 to 7 Hz for the S-61. The component specifications for the integrated tail rotor servo are designed to give an open-loop frequency response (current input to the EHV versus actuator velocity) that is nearly flat to 15 Hz. This will give a closed-loop response of 5 to 8 Hz, more than adequate to meet the control input requirements.

The ΔP regulating valve has little effect on the response characteristics of the integrated servo. Figure 20 shows the closed-loop frequency response of an integrated mechanical input servo. This data was collected from a nonlinear digital simulation of the servo. The simulation predicts the actuator and load inertias, the representative friction characteristics, the fluid compressibility, and the valve dynamics and non-linearities. The ΔP regulating valve designed for the integrated servo has a closed-loop time constant of approximately .01 second. The amplitude response of the servo is flat (within 3 dB) to 8 Hz. However, the regulation of friction and ΔP have produced an additional 20 degrees of phase lag at the -3-dB break frequency; i.e., 65 instead of 45 degrees of phase lag. The frequency at 45-degree phase lag is 5.7 Hz, which is quite satisfactory for pilot and SAS control responses.

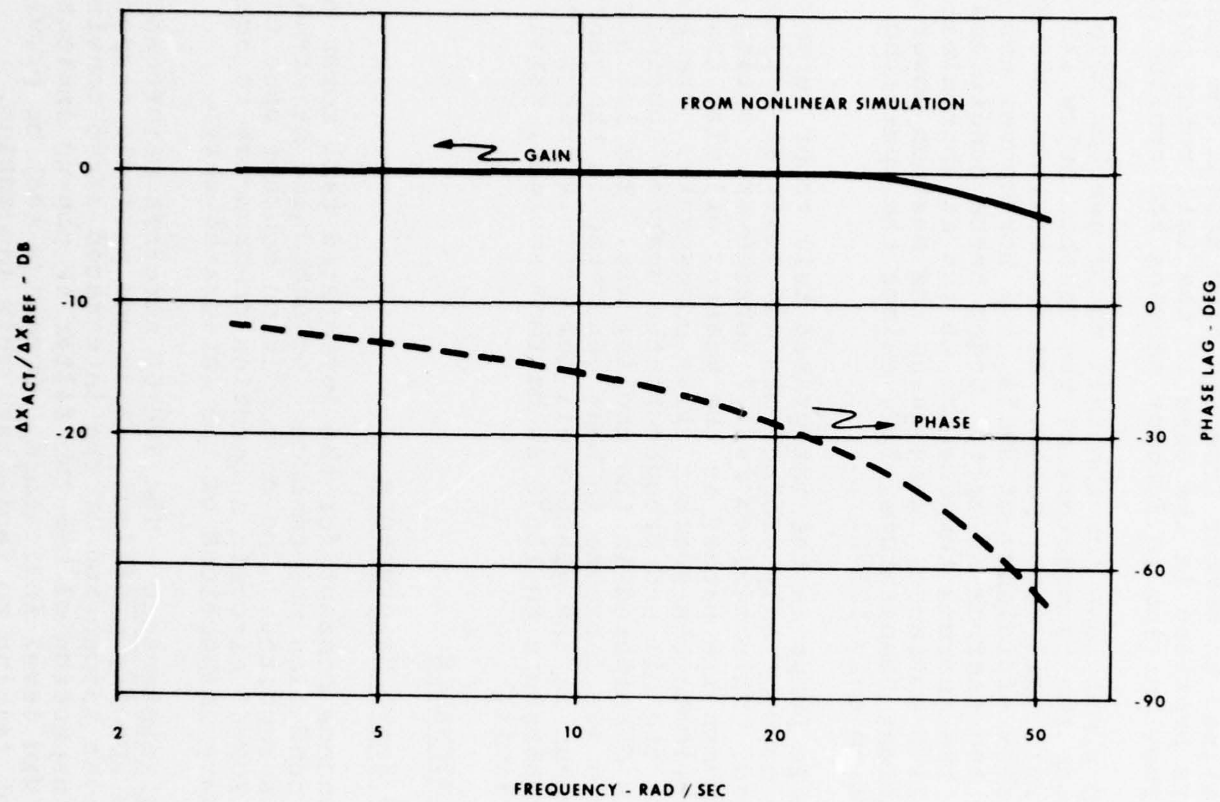


FIGURE 20. CLOSED-LOOP MECHANICAL-INPUT SERVO FREQUENCY RESPONSE.

THERMAL CHARACTERISTICS

The thermal energy created by the hydraulic pumps located in the tail rotor gearbox is dissipated by the gearbox cooling provisions of the current YUH-60 design. The gearbox housing is designed to be cooled conductively. The gearbox installation is designed to permit free air flow around the gearbox. Openings are provided in the base of the tail rotor pylon and at the gearbox fairing to further enhance the cooling air flow.

The cooling provisions for the tail rotor gearbox have been sized to keep the temperature of the gearbox below 145°C when absorbing full tail rotor power. At the maximum, 500 horsepower, with a gearbox efficiency of 99.5%, 2.5 horsepower are dissipated into the gearbox as heat. Under these conditions, tests have shown the gearbox temperature to run at approximately 70°C in a 21°C ambience. Even using the maximum power at the maximum ambient temperature, 52°, raises the operating temperature to only 101°C.

The hydraulic pumps in the integrated tail rotor servo ΔP regulation concept only produce maximum power at maximum control load. This maximum is 1.2 horsepower. During operation, the pumps are bathed in the gearbox oil mist that is used to lubricate the gearbox drive components. The heat is absorbed by the oil and brought to the gearbox housing where the heat is dissipated in the cooling air. The 1.2 horsepower represents a 48% increase in heat generated in the gearbox. A 48% increase in the gearbox oil temperature brings the gearbox temperature to 125°C at maximum ambient, still below the 145°C limit.

SYSTEM MAINTENANCE

Integrated Servo Maintenance

The maintenance concept for the integrated tail rotor servo is for on-condition maintenance. No scheduled maintenance or overhaul is required. The on-condition concept uses the specified YUH-60 aircraft inspection frequencies to accomplish the necessary inspections of the integrated servo.

Preventive Maintenance - The YUH-60 aircraft maintenance requirements specify preflight, daily and periodic inspections. The preflight inspection of the integrated servo consists of a visual inspection of the two filter ΔP pop-up indicators and the two fluid level indicators. Openings must be provided in the gearbox fairing to facilitate this inspection.

The daily inspection is a 1-minute check requiring the removal of the gearbox fairing and an inspection for oil leakage past seals, the security and integrity of the unit, the proper oil level, and any filter ΔP indications.

No periodic inspections are required.

No servicing of the servo is required with the exception of an occasional topping-off of the oil reservoir as determined through the daily inspection procedure.

Corrective Maintenance - Unscheduled removals of the Line Replaceable Unit (LRU), i.e., the integrated tail rotor servo, can be accomplished within the specified 0.5 elapsed hours. A second man should assist in the removal of the unit because of its weight (46.8 pounds) and length (36.2 inches) and the need to support the unit during its removal and installation.

Although all of the externally-accessible components could be replaced on the flight line, it is recommended that the only components that should be replaced are the filter, the filter ΔP indicator and the maintenance connectors. The replacements of these components would depend on visual indications of failures or malfunctions of the parts as determined during the scheduled aircraft inspections.

Tail Rotor Gearbox Maintenance

The integrated servo does not impose any unusual maintenance requirements on the tail rotor gearbox. Normal gearbox inspection and maintenance procedures are to be followed. Malfunctions within the integrated servo are isolated from the gearbox except for hydraulic fluid leakage into the gearbox. Internal leakage will be detected by an abnormal drop in the reservoir quantity indicator along with no visible external leakage and a corresponding abnormally high fluid level in the tail rotor gearbox sight gauge. Upon removal of the integrated servo for repair, the gearbox must be drained, flushed, and refilled.

SYSTEM ATTRIBUTES

The effectiveness of an integrated tail rotor servo can be seen by comparing the system with conventional systems having external hydraulic power sources. The quantitative values used in this study are based on estimates provided by Sikorsky for the baseline YUH-60 controls, Hamilton Standard for the integrated servo and General Electric Aerospace Controls for the fly-by-wire electronics. The system weight, recurring cost, reliability and survivability were determined for each of the following systems:

- the conventional YUH-60 mechanical control system
- the mechanical input integrated servo with conventional controls
- a fly-by-wire system with the fly-by-wire integrated servo
- a fly-by-wire system with conventional control and boost actuators

The conventional YUH-60 control system was described previously and is shown in Figure 1. The second configuration replaces the tail rotor servo and hydraulic supply lines in the conventional YUH-60 system with the mechanical input version of the integrated servo. The third configuration, the integrated servo fly-by-wire control system, has been described and is shown in Figures 2 and 3.

The fourth configuration replaces the integrated servo with a conventional fly-by-wire actuator configuration. The dual fly-by-wire control actuators driving the current YUH-60 tail rotor servo are shown in Figure 21.

The attributes of these four systems are summarized in Table 4. Other characteristics, such as performance, risk, and environmental sensitivity, are considered satisfactory for all configurations. A discussion of each of the attributes is given in the following paragraphs.

WEIGHT

The weight of the baseline conventional YUH-60 tail rotor control system is 77.1 pounds. This figure includes the new, lightweight, 29.7-pound tail rotor servo, 24.4 pounds of hydraulic system, and 23 pounds of mechanical control linkages and pilot boost. A breakdown of these weights is given in Table 5.

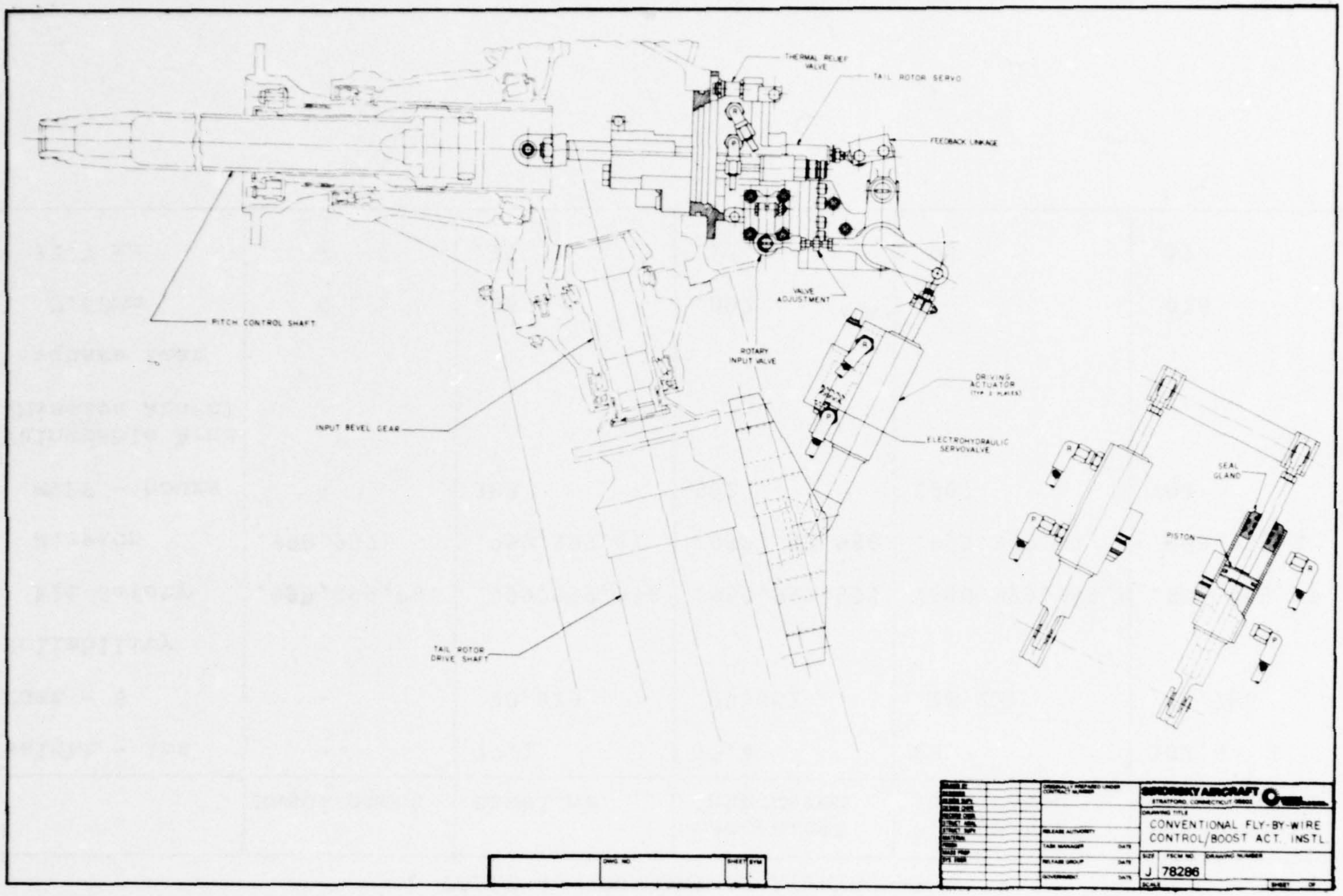


FIGURE 21. CONVENTIONAL FLY-BY-WIRE CONTROL INSTALLATION.

TABLE 4. SUMMARY OF ATTRIBUTES

	Requirement	Baseline	Mechanical Integrated	Fly-By-Wire Integrated	Fly-By-Wire Conventional
Weight - lbs	-	77.1	72.4	68.3	102.6
Cost - $	-	30,029	23,662	28,221	48,766
Reliability					
Flt Safety	.999,999,987	.999,999,978	.999,999,995	.999,999,999,9	.999,999,99
Mission	.999,937	.999,999,81	.999,999,986	.999,999,97	.999,999,3
MTBF - hours	-	388	582	2907	703
Vulnerable Area (Mission Abort)					
-square feet					
7.62mm	0	.06	.002	0	.078
12.7 mm	-	.15	.10	.05	.13

TABLE 5. BASELINE YUH-60 WEIGHT BREAKDOWN

Equipment	Component Weights (lb)	Weight (lb)
Total Mechanical Linkage		19.216
Cable Assy	3.172	
Pulleys (14)	3.64	
Quadrants (2)	2.2	
Mounting Hardware and Back-up Structure	10.204	
Pilot Boost Function		3.787
Total Tail Rotor Servo Instl		29.735
Servo	17	
Mounting	12	
Centering Spring	.735	
Total Tail Rotor Hydraulic System		24.4
Difference in Transfer Module	1.0	
First-Stage Tail Rotor Module	1.0	
Second-Stage Tail Rotor Module	.5	
Fittings (4)	.4	
Hydraulic Lines and Fluid	21.5	
Total Baseline		77.138

The mechanical integrated servo system replaces the conventional 29.7-pound tail rotor servo and 24.4 pounds of hydraulic lines with the mechanical input integrated servo at 49.4 pounds. The total system weight for this configuration becomes 72.4 pounds, a savings of 4.7 pounds.

The fly-by-wire integrated servo system uses the 46.8-pound integrated servo and 21.5 pounds of electronics and wiring to replace the entire conventional system. The integrated servo fly-by-wire system weight is 68.3 pounds.

The conventional fly-by-wire system adds two 13.5-pound fly-by-wire actuators and 21.5 pounds of electronics to the conventional YUH-60 system. The 23 pounds of mechanical linkage and pilot boost are removed, making the system weigh 102.6 pounds.

Table 6 compares the weights of the four configurations.

COST

The cost estimates in this study were based on recurring costs for quantities of greater than 250 units. The economic base was 1976 dollars. The $30,029 cost of the conventional YUH-60 tail rotor system is divided into $8025 for the tail rotor servo, $13,724 for the hydraulic components, and $8280 for the mechanical control linkages.

In the second study configuration, the $15,381 mechanical input integrated servo replaces the $8025 YUH-60 tail rotor servo and the $13,724 of hydraulic components. Total system cost is $23,661.

The $21,266 integrated fly-by-wire servo and the $6955 of electronics replace the entire $30,150 YUH-60 tail rotor control system. The total system cost is $28,221.

The conventional fly-by-wire configuration uses two $10,031 actuators and $6955 of electronics to replace the $8280 mechanical linkages. The total system cost is $48,766.

Table 7 compares the system recurring costs for the four configurations.

TABLE 6. WEIGHT COMPARISON OF TAIL ROTOR CONTROL CONFIGURATIONS

	Baseline	Mechanical Integrated	Fly-By-Wire Integrated	Fly-By-Wire Conventional
Mechanical Control Linkage	19.2	19.2	-	-
Hydraulic Supply Components	24.4	-	-	24.4
Pilot Boost	3.8	3.8	-	-
Tail Rotor Servo	29.7	49.4	46.8	29.7
Fly-By-Wire Control Actuators	-	-	-	27.0
Fly-By-Wire Electronics	-	-	21.5	21.5
Total - lbs	77.1	72.4	68.3	102.6

TABLE 7. COST COMPARISON OF TAIL ROTOR CONTROL CONFIGURATIONS

	Baseline	Mechanical Integrated	Fly-By-Wire Integrated	Fly-By-Wire Conventional
Mechanical Control Linkage	8,280	8,280	-	-
Hydraulic Supply Components	13,724	-	-	13,724
Tail Rotor Servo	8,025	15,381	21,266	8,025
Fly-By-Wire Control Actuators	-	-	-	20,063
Fly-By-Wire Electronics	-	-	6,955	6,955
Total - $	30,029	23,661	28,221	48,766

RELIABILITY AND MAINTAINABILITY

This section establishes reliability and maintainability attributes for each configuration for comparative evaluation. Table 8 gives a summary of the reliability estimates for each configuration. A Failure Modes and Effects Analysis (FMEA) is presented in Appendix B for the integrated power module fly-by-wire version and for the electrical linkage system. Appendix C contains maintenance frequency and corrective maintenance data.

Reliability Ground Rules

1. Reliability calculations involve only portions of the tail rotor control systems included in one or more of the configurations. This includes the control system equipment from the tail rotor mixer to the tail rotor, the pilot boost servo and the tail rotor hydraulic system.

2. Flight safety is maintained under degraded operation provided both following conditions are met:

   - The failure or loss of both tail rotor control systems results in a fail-safe self-centering mode.

   - The failure transients and pilot corrective actions required meet the requirements of MIL-H-8501A.

   These conditions can be tolerated because of the high sideslip stability resulting in the capability of safe forward flight with centered tail rotor pitch.

3. Mission completion is possible with one failed system. Mission abort is assumed after two failures when the degraded fail-safe level occurs.

4. Failure rates are based on UTTAS design specifications, FMEA (SER-70567), on estimates provided by Hamilton Standard Division of United Technologies Corporation for the power module and by General Electric for the electrical linkage system (F-B-W), and on MIL-HANDBOOK-217B for an inhabited aircraft environment over the temperature range of -55 to 71°C.

5. For the fly-by-wire configurations, an assumption is made that 50% of the electronic failures result in hardover signals at the failure point while 50% result in passive or null failures.

TABLE 8. RELIABILITY ATTRIBUTES

	Goal	Baseline	Mechanical Integrated	Fly-By-Wire Integrated	Fly-By-Wire Conventional
Total Failure Rate-per 10^6 hrs	-	2573	1718	344	2573
MTBF - hrs	-	388	582	2907	703
Flight Safety Reliability	.999,999,982	.999,999,978	.999,999,995	.999,999,999,989	.999,999,99
Mission Completion Reliability	.999,937	.999,999,81	.999,999,986	.999,999,97	.999,999,3

Target Reliability

The targets for flight safety reliability and mission completion reliability are determined as follows. The tail rotor control-axis reliability allocation is determined from the total system target by assuming equal contributions to the failure rates from the four control axes. Then, this allocation is assumed to have equal contribution from the portion of the tail rotor control system that remains unchanged (i.e., forward of the yaw mixer) and from the portion affected in the configuration studies. The resulting allocations for these configurations are:

	Total System Allocation	Partial Tail Rotor Control Allocation
Flight Safety Reliability	.999,999,9	.999,999,982
Mission Completion Reliability	.999,62	.999,937

Baseline - Conventional YUH-60 Tail Rotor Control

Reliability - The failure rate and the failure mode portions of the baseline system involved in this study are summarized in Table 9. The mechanical linkage failure rate is 1283 in 10^6 hours, but only 95 in 10^6 hours cause the loss of a control function or hardover since the degraded performance caused by most failures results in corrective action prior to catastrophic failure. The pilot boost servo is assumed to have no hardover or lockup mode, and the hydraulic supply is assumed to only fail by losing pressure. Thus, only the linkage and the tail rotor servo are assumed to have single-system hardover failure modes. It is assumed that 25% of servo failures cause the loss of a control function and that 50% of these are hardover failures. The flight safety in the baseline is provided by the dual linkage and the dual tail rotor servo designs so that the worst case, single hardover-type failure results in an opposing force from the other system. However, the most common failure is the loss of one system due to a loss of hydraulic pressure. The reliability diagrams of Figure 22 are used to compute the safety and the mission completion reliabilities shown in Table 8. The safety reliability of .999,999,978 is only slightly less than the target, and the .999,999,81 mission reliability far exceeds the target.

Maintenance - The maintenance of the baseline design consists of periodic visual inspections for mechanical integrity, slop or backlash, and hydraulic leaks, and control performance tests of the hydraulic systems conducted on a preflight basis.

TABLE 9. SUMMARY OF FAILURE RATES FOR THE BASELINE YUH-60 SYSTEM*

Equipment	Total	One System Loss of Control	One System Hardover
Mechanical Linkage - occurrences per 10^6 hrs	1283	48	24
Pilot Boost Function	211	-	-
Tail Rotor Servo	413	50	25
Tail Rotor Hydraulic System (System Pumps Only)	666	333	-
Total	2573	431	49

*Assumptions:

1. The equipment included everything from the yaw mixer to the tail rotor servo and the pilot boost.
2. Twenty-five percent of tail-rotor-servo failures cause loss of the function of one system.
3. Fifty percent of loss-of-function failures are hardovers of one system.
4. The hydraulic system failure rates are negligible except for pumps. The pump failure rate is based on experience.
5. Single failure points, if any, are neglected.

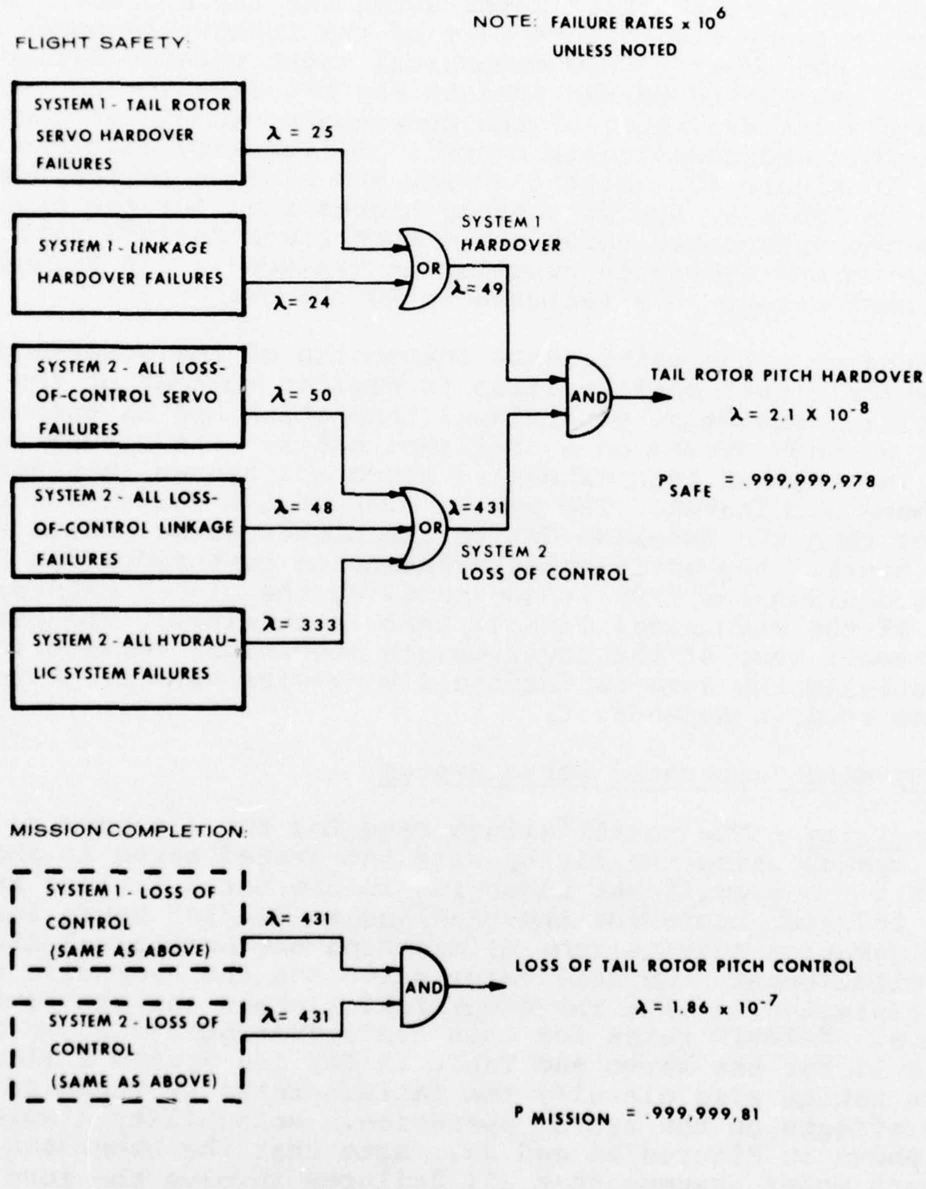


FIGURE 22. RELIABILITY DIAGRAM OF BASELINE YUH-60 SYSTEM.

Mechanical Control Input Integrated Servo Control System

Reliability - The total failure rates for this configuration are shown in Table 10. Failure rates of the mechanical linkage and the pilot boost are the same as for the baseline, while the failure rates of the tail rotor servo and the hydraulic system are replaced by the failure rate of the integrated power module. The power module mechanical input version failure rate is assumed to be the same as for the fly-by-wire version since the failure rates of the components removed or added are negligible and essentially cancel. Reliability diagrams are shown in Figure 23. Flight safety and mission reliability, shown in Table 8, are noticeably higher than for the baseline since the integrated servo has a much lower failure rate than the servo and hydraulic supplies it replaces: 225 failures in 10^6 hours versus 1079 failures in 10^6 hours.

Maintenance - The maintenance inspection of the power-module mechanical-input configuration is similar to that of the baseline, consisting of a visual inspection and an operational check of each system on a preflight basis. The visual inspection is somewhat less extensive since all hydraulic plumbing has been eliminated. The system MTBF of 582 hours is slightly higher than the baseline due to the higher power module MTBF, 4464 hours. Any anticipated maintenance cost reduction is limited since the MTBF is dominated by the higher maintenance cost of the mechanical linkage that is retained. The removal and repair cost of the power module mechanical version is essentially the same as for the fly-by-wire version, which is broken down in Appendix C.

Fly-By-Wire Integrated Servo System

Reliability - The total failure rate for the fly-by-wire control system using the fly-by-wire integrated servo is shown in Table 8. A significant reduction in the total failure rate from $2573/10^6$ hours for the baseline to $344/10^6$ hours for this configuration results from eliminating the mechanical linkage, the pilot boost, the tail rotor servo and the hydraulic system, and replacing it with the electrical linkage and the power module. Failure rates for this configuration are shown in Table 11 for the servo and Table 12 for the system's electronics. These tables also classify the failure rates by their failure mode effects on the system operation. Reliability diagrams are shown in Figures 24 and 25. Note that the breakdown of failure modes assumes that all failures involve the loss of function. The baseline breakdown in Table 9 assumed that most of the failures required maintenance action but did not degrade system operation. The loss of function assumption may be pessimistic for the integrated servo, although the probability of the early detection of mechanical failures is lower due to

TABLE 10. SUMMARY OF FAILURE RATES FOR THE INTEGRATED SERVO WITH MECHANICAL INPUT*

Equipment	Two System Total -per 10^6 hrs	One System - per 10^6 hrs	
		Loss of Control	Hardover
Mechanical Linkage	1283	48	24
Pilot Boost Function	211	-	-
Power Module	224	71.82	23.58
	1718	119.82	47.58

*Assumptions:

1. The mechanical linkage failure rates are the same as for the baseline.

2. The power-module, mechanical-input version failure rates are not significantly different from those for the fly-by-wire version.

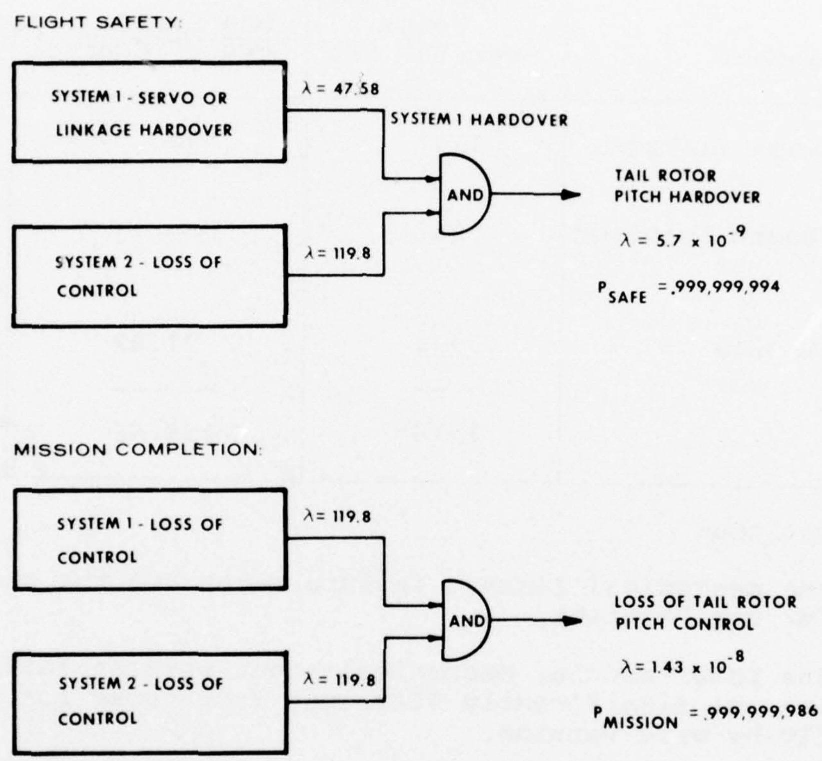


FIGURE 23. RELIABILITY DIAGRAM OF INTEGRATED SERVO WITH MECHANICAL INPUT.

TABLE 11. SUMMARY OF FAILURE RATES FOR THE INTEGRATED TAIL ROTOR SERVO, FLY-BY-WIRE VERSION*

Equipment	Two System Total - per 10^6 hrs	For One System - per 10^6 hrs		
		Loss of Control	Hardover	Loss of Fault Detect
Sump	6.92	3.46	-	-
Sump Relief Valve	.644	.322	-	-
Pump	48.4	24.2	-	-
External Connections	1.932	.966	-	-
Filter	.72	.36	-	-
Relief Valve	1.572	.786	-	-
ΔP Regulator	1.572	-	.786	-
Solenoid	18.848	4.924	-	4.5
Shuttle Valve	.868	.434	-	-
ΔP Transducer	2.268	-	-	1.134
Actuator Assy	85.862	25.0	10.0	7.931
EHV	26.448	3.224	9.5	.5
Bypass Valve	26.596	7.50	3.298	2.5
Filter Indicator	1.288	.644	-	-
Total Failure Rate	223.93	71.82	23.58	16.56
Failure Rate for one system	111.97			
MTBF for two systems - hrs	4465			
MTBF for one system - hrs	8931			

*Assumption:

1. Loss of control, hardover and loss of fault detection are based on 100% of total failures. Note that this is pessimistic compared to the baseline mechanical system.

TABLE 12. SUMMARY OF FAILURE RATES FOR THE ELECTRICAL LINKAGE SYSTEM, FLY-BY-WIRE CONFIGURATION*

Failure Mode	Each System - per 10^6 hrs
Actuator Control Circuit	
Active - Hardover	8
Passive - No Output	8
Monitor Control Circuit	
Active - Failure to Detect	22
Passive - Nuisance Fault	22
Total Each System	60
Total two systems	120
MTBF for two systems	8333

*Assumptions:

1. Electronic components are "M" level, "JAN" or MIL-STD-883. Note that lower failure rates can be attained by the use of higher reliability components at increased cost.

2. All failures fall into one of the above modes. A 50-50 distribution was used between active and passive.

3. A hard-mounted, -55 to 71°C, inhabited aircraft environment is used.

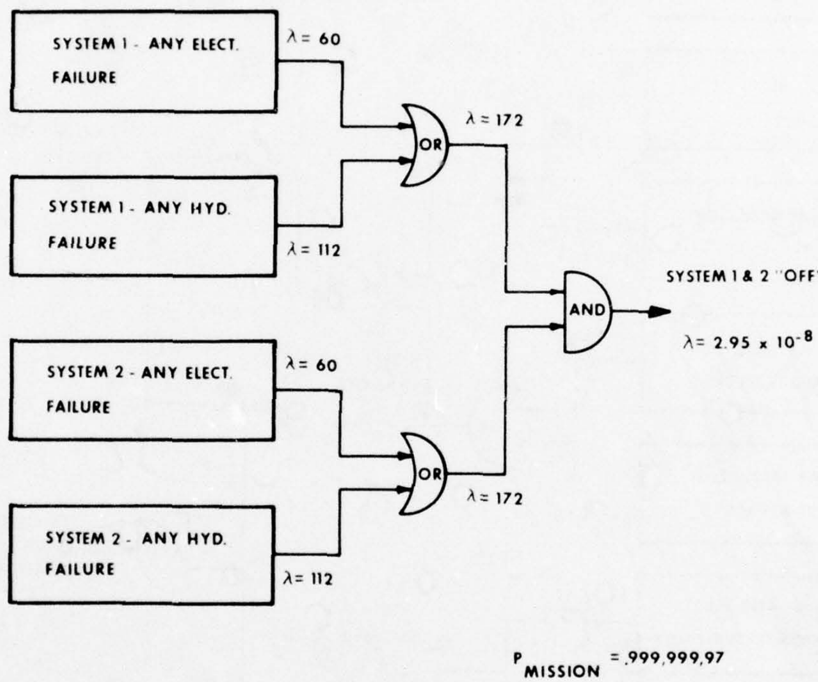


FIGURE 25. MISSION COMPLETION RELIABILITY DIAGRAM OF FLY-BY-WIRE INTEGRATED SERVO.

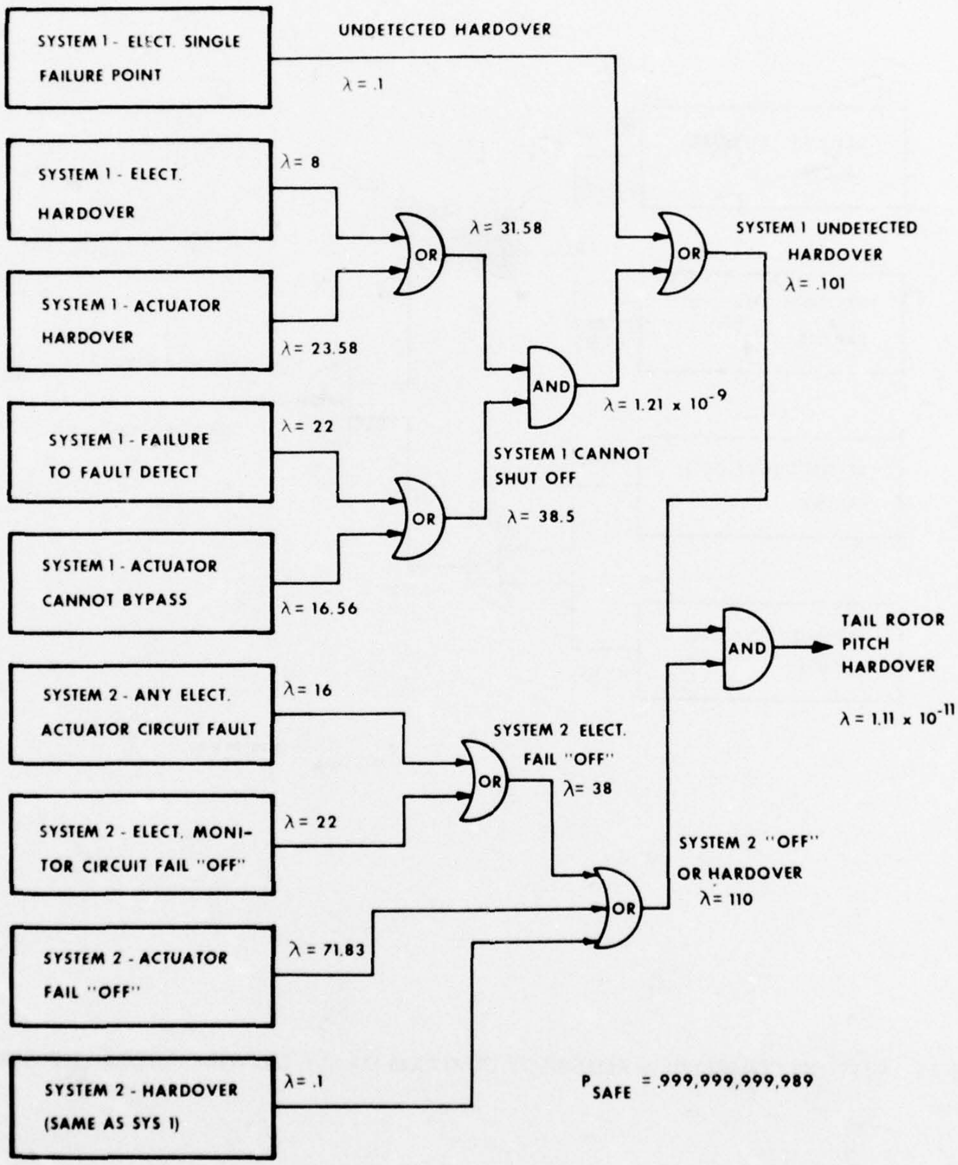


FIGURE 24. SAFETY RELIABILITY DIAGRAM OF FLY-BY-WIRE INTEGRATED SERVO.

the enclosed, self-contained nature of the integrated servo compared with the separation and the exposed nature of the baseline servo. Also, the detection of impending electronic failures is generally not possible, so that a functional failure usually occurs prior to detection. These two factors justify the somewhat conservative approach to the failure rate breakdown.

Flight safety reliability is achieved by built-in fault detection (or BITE) for each system combined with the two-system redundancy. This results in the automatic shutdown of the failed system following most single failures and eliminates failure transients and the need for the pilot to make corrective actions. In the event of a single or multiple failure of one system that causes that system to become hardover, the redundant system provides an opposing force, and the failure transient is then similar to a single hardover in the baseline. Pilot action is to disengage the failed system. Flight safety while operating on one system is then provided by its built-in fault detection.

As a result of in-flight fault isolation and detection, as well as system redundancy and improved component reliability, the flight safety reliability of .999,999,999,989 far exceeds the target of .999,999,982.

The mission completion reliability of .999,999,97 is based on the probability of one of two systems operational and far exceeds the target.

Maintenance - Maintenance for this configuration should consist of a visual preflight inspection of the equipment located at the tail rotor transmission and a performance test of each hydraulic or electrical system. The test should be done by the pilot as part of his preflight and requires turning each system off and on while verifying tail rotor control operation on the remaining system and checking to see that no faults are indicated. The time required for this operational check is about 15 seconds. An additional test of the fault detection system (BITE test) is recommended at intervals of approximately 10 hours. This test would be conducted by one man operating the BITE selector switches and observing the BITE indicators. These switches and indicators are to be located on each electronic box, which should be readily accessible, preferably mounted in the cabin. Preflight and BITE tests together are intended to detect 85% of total system failures and 100% of failures that could impair tail rotor control.

The integrated servo MTBF is 4464 hours (8928 hours per system), and the electrical linkage MTBF is 8333 hours (16,666 hours per box), as given in Tables 10 and 11. These values represent significant improvements over the baseline system primarily due to hardware simplifications and design. Removal and maintenance times at each level are shown in the tables of Appendix C for the fly-by-wire version of the integrated tail rotor servo and the electrical linkage system. These tables show mean time between removal (MTBR) of 3484 hours for the power module and 6097 hours for the electrical linkage. These MTBR's are based on the equipment MTBF and a factor of 30% to 50% for increased removals due to maintenance-induced failures and incorrect fault isolations. As a result of the improved system MTBF of 2907 hours, the on-aircraft maintenance and inspection is drastically reduced from the baseline.

Note that the high safety and mission reliability of this configuration, including the automatic indication of most faults, could be used to justify much longer inspection intervals, particularly for the BITE test. However, in order to insure a high degree of safety in the operational maintenance environment, the conservative intervals presented here are recommended.

Conventional Fly-By-Wire System

Reliability - The failure rates of the portions of the baseline system and of the electrical linkage system required in this configuration are shown in Table 13. The reliability diagram is given in Figure 26. The mechanical linkage and the pilot boost failure rates are deleted and replaced by the electrical linkage failure rates, including the failure rate of a fly-by-wire control actuator, which is assumed to have a failure rate equivalent to that of the integrated power module fly-by-wire version. This gives an 8928-hour MTBF per control actuator. Although the driver actuator is a somewhat simpler unit than the power module, the separation of the actuator assemblies, along with the individual attachments, the linkage and the plumbing, tends to nullify any reduction in the failure rate. The separation of the control actuator was designed to reduce the system vulnerability to ballistic threat. The flight safety and the mission completion reliabilities exceed the targets, although the mission reliability is lower than the baseline.

Maintenance - The maintenance of the conventional fly-by-wire system is similar to that of the integrated servo fly-by-wire system except that visual inspections of the control actuator installation, the baseline tail rotor servo and the hydraulic system would replace the inspection of the integrated servo. The same intervals and test sequence would apply. However, the equipment removal and maintenance costs would be higher

because there are three separate mechanical assemblies and installations instead of one. The system MTBF of 703 hours is roughly twice that of the baseline and results from the elimination of the mechanical linkage.

TABLE 13. SUMMARY OF FAILURE RATES FOR THE CONVENTIONAL FLY-BY-WIRE SYSTEM*

Equipment	Total -per 10^6 hrs	One System -per 10^6 hrs Loss of Control	Hardover
Tail Rotor Servo	413	50	25
Tail Rotor Hydraulic System (System Pumps Only)	666	333	-
Electrical Linkage System (Fly-By-Wire)			
Driver Actuator	224	71.82	16.5
Electronics	109	30.22	4.11
	1412	485.02	45.61

*Assumptions:

1. The failure rates of the rotor servo and the hydraulic system are same as for baseline.

2. The electrical linkage system (fly-by-wire) failures are the same as for the integrated power module fly-by-wire electronics. The driver actuator is given a failure rate equal to the power module.

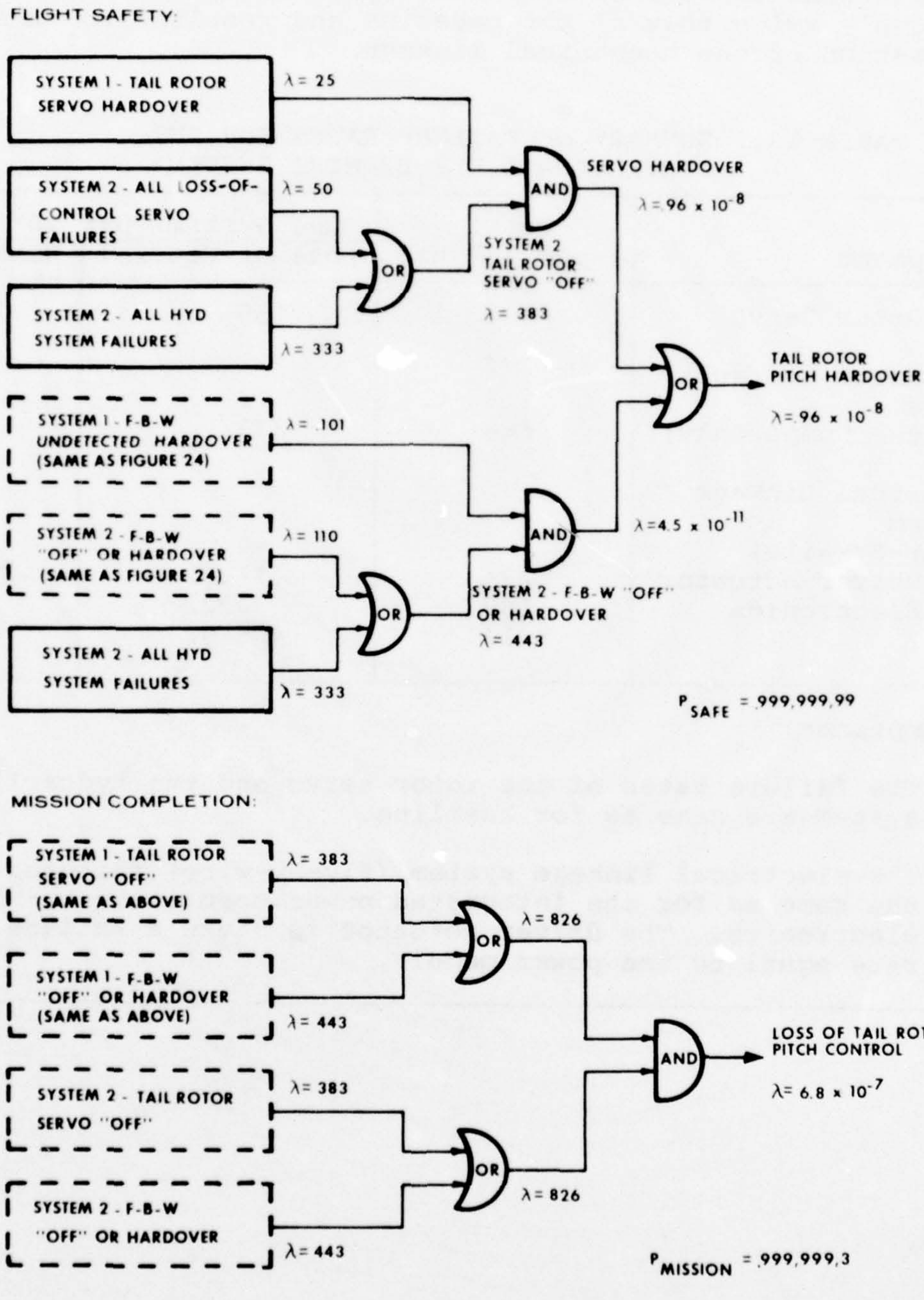


FIGURE 26. RELIABILITY DIAGRAM OF CONVENTIONAL FLY-BY-WIRE SYSTEM.

SURVIVABILITY

The UH-60A tail rotor control system is inherently survivable by design. The vulnerability of the alternate tail rotor control configurations was assessed using the guidelines in Reference 1. The primary threat considered in the study was a 7.62mm API projectile impacting at 2550 feet per second.

In general, if a severance causes a complete loss of control to the tail rotor, a centering spring blade restraint will drive the tail rotor servo to a null position. With the tail rotor blades thus positioned, forward flight may be attained from a hover and maintained sufficiently to effect a safe return to base. A mission abort kill was assessed for such damage.

Should a jam occur in the control system or the tail rotor servo while the aircraft is in forward flight, the aircraft will be controllable but unable to hover. A successful flight home with a roll-on landing can be achieved. If a jam occurs with the aircraft in a hover, the pilot will be able to transition to forward flight. The aircraft will be able to fly home, although not at maximum velocity. In either event, a mission-abort kill was assessed.

None of the proposed configurations appreciably affects the probability of losing the drive to the tail rotor. Therefore, aircraft reactions to this damage were not considered.

Table 14 summarizes the results of the vulnerability analyses performed. A mission abort was the most severe aircraft reaction possible.

Baseline YUH-60 Tail Rotor Control

There is almost no vulnerable area in the mechanical flight controls between the mixer and the tail rotor servo. The control rod material and the dimensions were chosen for tolerance to the primary threat. Tri-pivot connections are incorporated which have demonstrated retention of most control motion after ballistic impacts. The use of a redundant, spring-loaded control cable quadrant insures that control can be maintained even with one cable severed. The small vulnerable area assessed reflects the probability of severing both control cables in the pylon where their separation is least.

1 Bely, D., REVISED VULNERABILITY ANALYSIS CRITERIA FOR THE UTILITY TACTICAL TRANSPORT AIRCRAFT SYSTEM, Ballistic Research Laboratories, BRL IMR 407, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1975.

TABLE 14. AREAS VULNERABLE TO A SINGLE 7.62MM API PROJECTILE*

	Mechanical Controls	Electrical Controls	Hydraulic Lines	Conventional Servo	Servo in Shaft	Driving Servos	Pumps, Etc.	Total
Existing Configuration	.002	-	.043	.015	-	-	-	.060
Conventional Fly-By-Wire	-	0	.043	.015	-	.020	-	.078
Integrated Servo Power Module (Mechanical Input)	.002	-	-	-	0	-	0	.002
Integrated Servo Power Module (Electrical Input)	-	0	-	-	0	-	0	0

*Assumptions:

1. The areas given are measured in square feet and are averages of five views: front, rear, sides, and bottom.

2. The 7.62 mm API projectile is assumed to have a velocity of 2550 fps.

3. The areas given are those that, if hit, would cause a mission-abort kill.

he hydraulic lines to the tail rotor servo are the primary ontributors to the system's vulnerability. The area shown is for the severing of both hydraulic systems with a single round. Physical separation of the hydraulic systems has been used effectively to reduce the vulnerable area. Some further improvement is possible by nesting the aft hydraulic lines inside the cap of the pylon's aft spar, rather than centering them below the spar, where the only structures separating the two systems are the spar webs. In accordance with the guidelines, which assume the use of non-flammable MIL-H-83282 fluid, no probability of a hydraulic fluid fire was assessed.

The conventional servo design contains a small vulnerable area. Jams can be induced by ballistic impacts on the piston rods, the centering spring rod, or the centering spring housing. The spring itself was designed for 7.62mm tolerance. Separate steel housings for the two servo stages virtually eliminate the possibility of a leak in both hydraulic systems except for the chance of a round perforating both pressure switches or both relief valves. The areas calculated for those occurrences were insignificant. One feedback link may be severed by an impact but that stage can then be disengaged and tail rotor control can be maintained by the other.

Conventional Fly-By-Wire

The electrical system is essentially invulnerable to the 7.62-mm threat. The motion transducers that pick up control motions aft of the mixer and convert them to electrical signals are redundant and effectively separated. The electrical cables are at least as well separated as the mechanical cables of the existing system.

As with the existing system, the primary vulnerable components are the hydraulic lines. The small increase in area due to the branch lines running to the driving servos is insignificant.

The servo vulnerability is the same as in the existing configuration.

A detriment to the fly-by-wire configuration is the possibility of jamming either of the two control servos. The servos were assumed not to incorporate specific jam-proofing features. It was assumed that 50% of all impacts in critical areas would not cause a jam or would cause a jam that could be overridden. The remaining impacts were assessed as causing servo jams resulting in aircraft mission-abort kills.

The use of frangible pistons, liners, blands, and other jam-proofing provisions can significantly reduce the vulnerability of the control servos.

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The use of frangible pistons, liners, blands, and other jam-proofing provisions can significantly reduce the vulnerability of the control servos.

Integrated Servo Power Module (Mechanical or Electrical Control)

As noted previously, the electrical system is invulnerable and the mechanical system very nearly so to the primary threat.

The servo housed inside the tail rotor shaft is shielded by the gearbox housing, the flange, the output bevel gear shaft, and tail rotor shaft. The penetration of a 7.62mm projectile impacting at 2550 feet per second will be degraded or defeated by the surrounding structures before being able to perforate the servo housing. No vulnerable area was assessed for the servo.

The internal pumps, the valves, and the transfer tubes are shielded by the gearbox housing and the input bevel gear. Single projectiles penetrating the housing will be unable to disable components of both hydraulic systems, which are diametrically opposed and separated by the servo support link. The external components are similarly located so as to make perforation of both hydraulic systems highly unlikely.

Higher Threats

Table 15 shows a summary of estimated areas vulnerable to a 12.7mm API projectile impacting at 2500 feet per second. The vulnerability trends which emerge in upgrading the threat from 7.62mm to 12.7mm can be expected to continue for higher kinetic energy threats.

The mechanical controls, although tolerant to 7.62mm impacts, are susceptible to jams and severances by higher threats. This increased vulnerability is in the rods, the rod end fittings, and the joints. Techniques are presently being studied that will serve to harden mechanical flight control components to these threats.

The electrical controls do have some small vulnerability to higher threats. However, they can be made invulnerable to any kinetic energy threat simply by the addition of a third (out of plane) system.

The hydraulic lines show an increase in vulnerable area due strictly to the increase in projectile size.

Although the tail rotor servo still enjoys considerable masking from the surrounding components, the probability of suffering a jam is increased.

The servo in the shaft, which was effectively shielded from 7.62mm impacts, is vulnerable to 12.7mm and higher threats. Jams and loss of both hydraulic systems are possible.

TABLE 15. AREAS VULNERABLE TO A SINGLE 12.7MM API PROJECTILE*

	Mechanical Controls	Electrical Controls	Hydraulic Lines	Conventional Servo	Servo in Shaft	Driving Servos	Pumps, Etc.	Total
Existing Configuration	.05	-	.07	.03	-	-	-	.15
Conventional Fly-By-Wire	-	0	.07	.03	-	.03	-	.13
Integrated Servo Power Module (Mechanical Input)	.05	-	-	-	.04	-	.01	.10
Integrated Servo Power Module (Electrical Input)	-	0	-	-	.04	-	.01	.05

***Assumptions:**

1. **The areas given are measured in square feet and are averages of five views: front, rear, sides, and bottom.**
2. **The 12.7mm API projectile is assumed to have a velocity of 2500 fps.**
3. **The areas given are those that if hit, would cause a mission-abort kill.**

The control servos in the conventional fly-by-wire configuration are more susceptible to jamming due to the impact of a larger threat.

The pumps and other internal components are still well shielded and separated. There is some small increase in the probability of perforating both hydraulic systems.

SUMMARY OF ATTRIBUTE COMPARISONS

Mechanical Input Integrated Servo versus Baseline YUH-60 System

The mechanical input integrated servo enjoys a slight advantage over the baseline tail rotor control system in every attribute examined. The Table 4 attribute summary illustrates this fact. All of these savings are directly attributable to the elimination of the hydraulic components. Half of the baseline system cost is for the hydraulic supply components. The 50% increase in MTBF is also due to the elimination of the maintenance actions required by the hydraulic supply systems.

Conventional Fly-By-Wire versus Baseline YUH-60 System

The only advantage the conventional fly-by-wire tail rotor control system has over the baseline system is in system MTBF. Replacing the inexpensive mechanical input linkages with high technology electronic and electrohydraulic components increases both the cost and the weight. At the same time, these components eliminate the maintenance actions required by the mechanical linkages in favor of the more maintenance-free components, resulting in the 81% improvment in MTBF.

Fly-By-Wire Integrated Servo System Versus Baseline YUH-60 System

The fly-by-wire integrated servo configuration provides the most noteworthy improvements over the baseline system. For an equivalent cost, the fly-by-wire system using the integrated servo is 9 pounds, or 12%, lighter and has a 650% improvement in MTBF. The MTBF improvement is a result of removing both the mechanical and the hydraulic supply systems and their associated maintenance requirements. The resulting MTBF is similar to that of the baseline servo only, since the electrical linkage's MTBF is very long because of its simplicity. An additional advantage of this fly-by-wire configuration is that its mission-abort vulnerability to a 12.7-mm threat at 2500 fps is the same as the baseline's mission abort vulnerability to a 7.62 mm threat at 2550 fps.

Conventional Versus Integrated Servo Fly-By-Wire

When used in a fly-by-wire tail rotor control system, the integrated servo is lighter and less costly than the conventional system studied. However, the cost and the weight penalties paid by the conventional system could possibly be overcome by incorporating the electrical input function into the tail rotor servo. But, the MTBF difference is mostly a function of the external hydraulic supply, and the 300% improvement in system MTBF for the integrated servo system is directly attributable to simplifying the hydraulic supplies.

CONCLUSIONS

The preliminary design study results indicate that a control actuator with integral hydraulic power supplies can be successfully utilized for tail rotor control of a utility helicopter.

Sufficient hydraulic-power generation and regulation capabilities for two control stages can be packaged within the tail rotor gearbox envelope restrictions of the YUH-60A current-technology utility helicopter. The following specific conclusions are presented:

- The location of the hydraulic supply system within the tail rotor gearbox and the resultant removal of the hydraulic supply lines from the main rotor pumps improves the survivability of the YUH-60 due to a decrease in the presented vulnerable area.

- Replacing the current YUH-60 tail rotor servo with the mechanical-input version of the integrated servo provides a moderate weight reduction with a substantial price decrease.

- When used in a fly-by-wire system, the electrical-input integrated servo offers significant cost and weight savings when compared to a conventional fly-by-wire actuator system with a control actuator driving a boost actuator.

- The preliminary design of the integrated servo uses the existing YUH-60 tail rotor gearbox envelope. Additional protection from ballistic threats could be obtained by redesigning the tail rotor gearbox housing to permit wider spacing of system components and to make better use of the inherent shielding of the gearbox.

RECOMMENDATIONS

Based on the system studies conducted during this project and the conclusions presented, the following recommendations are offered.

- Continue the development of the integrated tail rotor servo concept through fabrication, ground testing and flight testing.

- The electrical-input version of the integrated servo should be the subject of the development program since it offers the most benefits and has greater application potential in future fly-by-wire systems.

- A concurrent study should be made of the benefits of more fully mating the tail rotor gearbox and integrated servo designs.

APPENDIX A

PRELIMINARY DESIGN SPECIFICATION FOR INTEGRATED TAIL ROTOR SERVO POWER MODULE

The design parameters for the Integrated Tail Rotor Servo are presented in this Appendix. They are presented in a design specification for the fabrication and qualification of a development article. The Integrated Servo described in this specification is the electrical input version for the fly-by-wire control system configuration described on page 10 of this report.

1. SCOPE

1.1 General

This specification establishes the performance, design, development and test requirements for an integrated tail rotor servo power module. This unit shall be designed to replace the Sikorsky S-70 helicopter tail rotor pitch control.

2. APPLICABLE DOCUMENTS

2.1 Documents

The following documents of the exact issue shown form a part of this specification to the extent specified herein. In the event of a conflict between a document referenced herein and the contents of this specification, the requirements of this specification shall be considered the superseding requirement. In other paragraphs of this specification, only the basic document number is stated. The revisions and changes for the applicable documents are identified only in this paragraph.

2.1.1 Specifications

2.1.1.1 Military

MIL-D-1000	Drawings, Engineering and Associated Lists
MIL-E-5007C(1)	Engine, Aircraft, Turbojet and Turbofan, General Specification for
MIL-E-5400P	Electronic Equipment, Airborne, General Specification for
MIL-H-5440G	Hydraulic System, Aircraft Type I and II Design, Installation, and Data Requirements
MIL-C-5501E(1)	Caps and Plugs, Protective Dust and Moisture Seal
MIL-C-5503C(3)	Cylinders, Aeronautical, Hydraulic Actuating, General Requirements for
MIL-G-5514F	Packings, Installation and Gland Design, Hydraulic, General Specification for
MIL-C-5541B(1)	Chemical Films for Aluminum and Aluminum Alloys
MIL-H-5606G	Hydraulic Fluid, Petroleum Base, Aircraft and Ordinance
MIL-E-6051D(1)	Electromagnetic Compatibility Requirements, Systems

MIL-H-6083C(2)	Hydraulic Fluid, Petroleum Base Preservative
MIL-S-6743(3)	Switches, Push Button and Limit
MIL-I-6866B(2)	Inspection, Penetrant Method of
MIL-I-6868D	Inspection Process, Magnetic Particle
MIL-P-6906B	Plates, Identification
MIL-F-7179(D)	Finishes and Coatings, General Specification for Protection of Aircraft and Aircraft Parts
MIL-S-7742B	Screw Threads, Standard, Optimum Selected Series, General Specification for
MIL-I-8500C	Interchangeability and Replaceability of Component Parts for Aerospace Vehicles
MIL-A-8625C(1)	Anodic Coatings for Aluminum and Aluminum Alloys
MIL-P-8651B	Plates: Identification and Modification (for Aircraft), Installation of
MIL-H-8775C	Hydraulic System Components, Aircraft and Missiles, General Specification for
MIL-F-8815B	Filter and Filter Elements, 15 Micron Absolute, Type II Systems
MIL-S-8879A	Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification for
MIL-Q-9858A	Quality Program Requirements
MIL-T-10727A	Tin Plating, Electro-Deposited or Hot Dipped for Ferrous and Non-Ferrous Metals
MIL-F-18372	Flight Control Systems: Design Installation and Test of, Aircraft (General Specification for)
MIL-P-25732B	Packing, Preformed, Petroleum Hydraulic Fluid Resistant 275°F
MIL-C-26074B(1)	Coating, Nickel-Phosphorus, Electroless Nickel, Requirements for
MIL-C-0026482F(1)	Connector, Electric, Circular, Miniature Quick Disconnect, Environment Resistant, General Specification for
MIL-H-83282A	Hydraulic Fluid, Fire Resistant Hydrocarbon Base, Aircraft
MIL-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, 275°F

2.1.2 Standards

2.1.2.1 Military Standards

MIL-STD-130D-1	Identification and Marking of U. S. Military Property
MIL-STD-143B	Standards and Specification, Order of Precedence for the Selection of
MIL-STD-210A(1)	Climatic Extremes of Military Equipment
MIL-STD-453(1)	Inspection, Radiographic
MIL-STD-461(a) (Change 6)	Electromagnetic Interference
MIL-STD-721B-1	Definitions of Effective Terms for Reliability, Maintainability, Human Factors, and Safety
MIL-STD-704A (Notice 3)	Electric Power, Aircraft, Characteristics and General Utilization of
MIL-STD-810B-4	Environmental Test Methods
MIL-STD-889A	Dissimilar Metals
MIL-STD-1472A	Human Engineering Design Criteria for Military Systems, Equipment and Facilities

2.1.2.2 Miscellaneous Standards

ANS B46.1	Surface Texture (American National Standards Institute, Inc)

2.1.3 Other Government Documents

AMCP 706-203	Engineering Design Handbook, Helicopters, Volume III, Qualification Assurance
AR 70-38	Research, Development, Test and Evaluation of Materials for Extreme Climatic Conditions
QQ-C-320A	Chromium Plating (Electro-Deposited)
QQ-N-290A	Nickel Plating (Electro-Deposited)
MIL-HDBK-5A-4	Metallic Materials and Elements for Aerospace Vehicle Structures
AFFDL-TR-69-111	Fracture Mechanics Guidelines for Aircraft Structural Applications
USAMRDL-TR66-9	Fatigue Crack Propagation in Aircraft Materials

MIL-HDBK-17A (Part I)	Plastic for Aerospace Vehicle, Part 1 Reinforced Plastics
MIL-HDBK-23A	Structural Sandwich Composites

2.1.4 Department of the Army Supply Catalogs

SC-5180-99-CL-A01	Tool Kit, Aircraft Mechanics, General
SC-5180-99-CL-A02	Tool Kit, Aircraft Repairmen's, Army Aircraft
SC-5180-99-CL-A03	Tool Kit, Hydraulic Repairman's, Army Aircraft

2.1.5 Sikorsky Documents

DS-512-3-4	Integrated Tail Rotor Servo Power Module

3. REQUIREMENTS

3.1 Item Definition

The module shall be a completely integrated unit, deriving its power from the tail rotor shaft and producing output displacements, at a high force, in proportion to the electrical input signals. The module shall be completely redundant and shall be designed in accordance with MIL-H-5440, MIL-H-8775 and MIL-E-5400. All performance characteristics and requirements of Paragraph 3 herein shall be met under all environmental and operating conditions, including rotor speeds from 80 to 125 percent of rated speed. An optional version of the module shall receive mechanical inputs in place of electrical inputs.

3.1.1 Item Schematic

The item schematic shall be as defined by Figure A-1 herein.

3.1.2 Item Interface

3.1.2.1 Physical Interface

The physical interface shall be as defined on the specification control drawing DS 512-3-4.

3.1.2.2 Electrical Interface

The electrical interface shall be as defined in Figure A-2 herein.

3.1.2.3 <u>Functional Interface</u>

3.1.2.3.1 Electric Power - The actuator shall meet the specified performance requirements when supplied with 28 VDC electric power conforming to MIL-STD-704, Category B.

3.1.2.3.2 Electric Interfaces and Circuits - A simplified block diagram of the electrical interfaces of the actuator is shown in Figure A-2. The block diagram illustrates the redundancy of the actuator. The electric circuits used in each channel of the equipment shall be as shown in the circuit schematic, Figure A-3. The circuit schematic provided by the supplier shall include identification of each circuit function, the wire sizes and color codes, the connector pins, the shielding and the twisting.

3.1.2.3.3 Hydraulic Interface - There shall be no requirement for hydraulic interface. All hydraulic systems and subsystems that are required for the correct operation of the module shall be contained within the module.

3.1.2.3.4 Mechanical Interface - The module shall interface with the S-70 tail rotor gearbox and rotor system as required to properly function as an integrated tail rotor servo. The speed of the rotor shaft shall be 1189 rpm at 100 percent of rated speed. The normal operating temperature of the tail rotor gearbox is $167^{\circ}C \pm 9^{\circ}C$. The maximum operating temperature is $29\overline{3}^{\circ}F$. Gearbox lubricating oil is per MIL-AL-7808 or MIL-AL-23699.

3.1.2.4 <u>Rated Operating Pressure</u>

The rated operating pressure shall be proportional to the applied load. The maximum rated operating pressure shall be 3000 psi at rated tail rotor speed.

3.1.3 Components

The system shall comprise two stages. Each stage shall contain, but not be limited to, the following components and features:

(a) Reservoir, which may be common with priority separation
(b) Filtration with differential pressure indicators
(c) Relief valves
(d) Pump
(e) Electrohydraulic servo valves
(f) Piston position transducers
(g) Devices indicating correct system operation at remote locations (SYSTEM BYPASS SIGNAL)
(h) Differential pressure transducer
(i) System engage/disengage valve
(j) Facilities to pressurize system from an external source
(k) Servo valve second stage spool position transducer

3.1.4 Government-Furnished Property List

Not applicable.

3.1.5 Government-Loaned Property List

Not applicable

3.2 Characteristics

3.2.1 Performance

Unless otherwise specified, values set forth to establish requirements for performance apply to performance under both standard conditions and all combinations of the environmental conditions specified herein. Compliance with Section 3 requirements shall not relieve the supplier of the responsibility of satisfying the performance requirements specified in the following paragraphs.

3.2.1.1 Standard Conditions

Unless otherwise specified, the actuator performance requirements apply under the following standard conditions:

Fluid: MIL-H-5606 or MIL-H-83282
Ambient Temperature: 100°F
Drive Train Speed: 1189 rpm
Electrical Excitation: 28 VDC per MIL-STD-704, Category B
Rated Electrohydraulic servo-valve drive current: $\pm$ 4 ma

3.2.1.2 Leakage

3.2.1.2.1 External Operating Leakage

External leakage past dynamic seals shall not exceed one drop per 100 cycles at full-stroke to 1/4-stroke cycles or one drop per 1000 cycles at amplitudes below 1/4 stroke. The requirement applies at unit operating temperatures between 0 and +275°F with normal operating pressure. External leakage shall not exceed one drop per 25 cycles at module temperatures between -65 and 0°F. Where a failed dynamic seal could allow contamination of the gearbox lubrication fluid with MIL-H-5606 or MIL-H-83282 fluid, adequate measures shall be taken to vent such leakage overboard.

3.2.1.2.2 Static External Leakage

External leakage shall not exceed one drop per hour past any dynamic seal while the unit is stationary. This requirement shall apply at unit temperatures between -65 and +275°F and ambient temperatures between -65 and +160°F. The requirement of 3.2.1.2.1 concerning gearbox lubrication fluid contamination applies.

3.2.1.2.3 Static Seal Leakage

There shall be no leakage from any static seal under any operating, nonoperating or environmental condition.

3.2.1.2.4 <u>Internal Leakage</u>

The internal leakage of the module shall be kept at a minimum to minimize the unit's overall power consumption and heat rejection.

3.2.1.3 <u>Stroke</u>

The unit shall provide a stroke of 3.550 ± .050 inches.

3.2.1.4 <u>Piston Velocity</u>

The maximum unit piston velocity shall be 3.75 ± 0.25 in./sec extend or retract with no externally applied load. The piston velocity with an applied load equal to one-half of the actuator's stall load shall be 69 ± 5 percent of the no-load velocity. These velocity requirements shall be met for any rotor speed between 80 and 125 percent of rated.

3.2.1.5 <u>Output Force</u>

The module shall provide an output force of 2100 (±50) lbs per stage at stall for any rotor speed between 80 to 125 percent of rated.

3.2.1.6 <u>"No-Load" Open-Loop Operation</u>

3.2.1.6.1 <u>Velocity Gain</u>

The module's continuous velocity curve shall meet the following limits within the rated signal range:

Rated signal (ma)	± 4
Maximum slope $\frac{\%/sec}{ma}$	31.25
Minimum slope	25.0
Nominal slope	28.1

3.2.1.6.2 Hysteresis

The velocity hysteresis, defined as the maximum difference in the driving signal required to obtain piston velocities in a given direction on increasing and decreasing signal levels, shall not exceed 5 percent of the rated signal. For inputs less than the rated input current, hysteresis shall not exceed 2.0 percent plus 3.0 percent of the applied input.

3.2.1.6.3 Threshold

The velocity threshold, defined as the increase in the signal level required to obtain a measurable change in velocity in a given direction, shall be less than 1.0 percent of the rated signal in the operating signal range beyond null. The signal change required to reverse piston motion shall not exceed 2.0 percent of the rated signal.

3.2.1.6.4 Null Bias

The module shall require less than 2.5 percent of the rated signal to hold the piston motionless at any point within its travel at standard conditions.

3.2.1.6.5 Null Shift

The module's maximum null shift from null bias at standard conditions shall not exceed the following limits:

(a) Temperature variations from -65 to +275°F: 3 percent of the rated signal
(b) Supply pressure variations, $P_S \pm 15$ percent psid: 2.5 percent of the rated signal
(c) Return pressure variations, $P_R \pm 15$ percent psid: 2.0 percent of the rated signal
(d) Accelerations to $\pm$ 10 g: 0.5 percent per g.

3.2.1.6.6 Open Loop Frequency Response

The actuator frequency response characteristics shall be within the limits shown in Figure A-4. Furthermore, the actuator phase lag shall not exceed 90 degrees at 5 percent of the rated signal amplitude and 3 Hz valve driving signal.

3.2.1.6.7 Linearity

The output to input relationship (inches/sec/ma) shall be linear within 2 percent over the entire stroke.

3.2.1.6.8 Stability

The module shall exhibit no instabilities anywhere in the operating range when operating in either the single- or dual-stage mode and when connected to a load having the following characteristic transfer function:

$$\frac{\text{Actuator Load (lbs)}}{\text{Actuator Displacement (in.)}} = \frac{500}{.00006\, S^2 + .03S + 1}$$

3.2.1.7 Design Pressures

The design pressures, in psig, shall be as follows:

A. Working Pressure

1.	Pressure	3000 psi
2.	Return	12 to 65 psi
3.	Reservoir	12 to 65 psi

B. Proof Pressure

1.	Pressure	4500 psi
2.	Return	2250 psi
3.	Reservoir	110 psi

C. Burst Pressure

1.	Pressure	7500 psi
2.	Return	4500 psi
3.	Reservoir	220 psi

D. Impulse Pressure

1.	Pressure	4500 psi
2.	Return	2250 psi
3.	Reservoir	N/A

3.2.1.8 <u>Servo-Valve Pressure Gains</u>

The servo valve's no-flow pressure gain at frequencies below cut-off shall be 25 percent of the supply pressure per 1 percent of the servo-valve input.

3.2.1.9 <u>Servo Dynamic Stiffness</u>

The servo actuator's dynamic stiffness at frequencies above cut-off shall be 80,000 lbs/in. using a fluid bulk modulus of 150,000 psi.

3.2.2 <u>Physical Characteristics</u>

3.2.2.1 <u>Unit Weight</u>

The unit weight shall not exceed 48 lbs (dry weight).

3.2.2.2 <u>Envelope</u>

The unit shall not exceed the envelope and outline dimensions shown in drawing DS-512-3-4.

3.2.2.3 <u>Fatigue Life</u>

Each stage of the module shall be capable of sustaining the loads listed below:

1. 10^8 cycles of a 2000 $\pm$ 200-lb load applied externally to the module output in tension or compression and reacted hydraulically by one stage through the module housing without evidence of external leakage, performance degradation, or permanent deformation.

2. 10^5 cycles of a 100 $\pm$ 2000-lb load applied externally to the module output in tension and hydraulically reacted by one stage through the servo housing without evidence of external leakage, performance degradation or permanent deformation.

3. The unit shall withstand 10^6 impulse cycles in the high pressure circuit of the module. These cycles result from the turn-on and turn-off operations of each stage and the subsequent pressure spikes that are associated with the rapid valve operation time.

4. The unit shall withstand 2×10^4 start and stop cycles. Acceleration rates shall be 20 percent of the maximum speed per second.

3.2.2.4 Load Factor

During operation, the module and all its components shall be capable of sustaining a load factor of 10 g's in any direction without permanent deformation or any performance degradation.

3.2.2.5 Insulation Resistance

The insulation resistance between each connector pin and the actuator body shall be greater than 500 megohms (measured with 500 volts dc applied for one minute) following a 1-minute application of 1000 volts RMS at 60 Hz to each connector pin. Testing shall be performed at room temperature and humidity conditions.

3.2.2.6 External Adjustments

The unit shall be adjusted to meet this specification prior to installation. If external adjustments are utilized, they shall be sealed with inspection stamps. The unit shall not require adjustment once installed on the aircraft.

3.2.2.7 Seal Glands

All seal glands shall be in accordance with MIL-G-5514 except piston-head seal grooves.

3.2.2.8 Seals

Piston rings shall be used for the piston-head seals. Two-stage external piston-rod seals shall be employed with the cavity between the two seals vented to return. The piston-roll seals shall use a filled Teflon slipper seal on the high-pressure side and an elastomer seal on the low-pressure side. Elastomeric seals shall conform to MIL-P-25732, MIL-P-83461 or MS 28775. Sealing shall not be accomplished by crushing. O-rings designated by MIL-G-5514 for static application only shall not be used.

3.2.2.9 Back-Up Rings

Back-up rings, when used, shall be installed on both sides of the O-ring. Back-up rings shall conform to MS 28774 when used with MS 28775 O-rings. When MIL-P-83461 compound rings are used, MS 28774 back-up rings cannot be used.

3.2.2.10 Internal Filtration

All orifices or restrictions in fluid circuits wherein the smallest cross-sectional dimension is less than 0.070 inch and the clogging of which could cause malfunction of the item, shall be protected by a filter element having a screened opening of .006 to .010 inch. Filter elements must be strong enough to absorb the item's design flow and 150 percent of the supply pressure without rupture or permanent deformation.

3.2.2.11 Special Tools

The module shall be designed to be removed from the helicopter with the tools in Army supply catalogs SC-5180-99-CL-A01, SC-5180-99-CL-A02 and SC-5180-99-CL-A03.

3.2.2.12 Screw Threads

Screw threads shall be in accordance with MIL-S-8879 or MIL-S-7742. Except for standard parts that are approved by Sikorsky, only MIL-S-8879 threads shall be used.

3.2.2.13 Lubrication

Only MIL-H-5606 or MIL-H-83282 hydraulic fluid shall be used to lubricate seals during the installation and assembly of the module. The need for lubrication during the normal service life of the module is prohibited.

3.2.2.14 Scraper Rings

The actuator shall incorporate scrapers or boots at the exposed ends of the piston rod to preclude the introduction of external contamination in the seal area.

3.2.2.15 Safetying

All threaded parts shall be securely locked or safetied with safety wire, self-locking nuts or some other approved methods. Safety wire shall have a minimum diameter of 0.032 inch and shall conform to MS 20995. Safety wire shall be applied in accordance with MS 33540.

3.2.2.16 Structural Attachment

The module housing shall be rigidly attached to the helicopter tail rotor transmission housing with attachment bolts.

3.2.2.17 Separated Stages

The two module stages shall be structurally and hydraulically separated to prevent a crack in one stage from propagating to the other stage.

3.2.2.18 Air Removal

The module shall be self-bleeding to the greatest possible extent. Where self-bleeding is impossible or impractical, bleeding provisions shall be incorporated to facilitate the removal of air while the module is installed in the aircraft.

3.2.2.19 Ground Test Provisions

Provisions shall be incorporated to allow the module to be powered from an external source to permit the checkout of the module on the ground. Special self-sealing couplings or adapters may be used. Ground operation shall be performed with the rotor head stationary.

AD-A047 678 UNITED TECHNOLOGIES CORP STRATFORD CONN SIKORSKY AIR--ETC F/G 1/3
PRELIMINARY DESIGN STUDY OF AN INTEGRATED TAIL ROTOR SERVO POWE--ETC(U)
SEP 77 J R MACIOLEK, K WALLISCHECK DAAJ02-76-C-0056
UNCLASSIFIED SER-50798 USAAMRDI-TR-77-20 NL

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3.2.2.20 Survivability/Vulnerability Requirements

3.2.2.20.1 Threats

The threats shall be a 7.62mm API projectile impacting at 2550 fps or a 12.7mm API projectile impacting at 1600 fps anywhere on the vehicle (lower hemisphere +15 degrees).

3.2.2.20.2 Survivability

The module shall be capable of providing control and control power to the tail rotor for a minimum of 30 minutes after sustaining a hit anywhere on the module with a 7.62mm API projectile. No single-point hit or failure shall result in the loss of tail rotor control for either threat of 3.2.2.20.1.

3.2.2.20.3 Vulnerability

The vulnerable area of the module shall be kept to a minimum. The shielding effect of the gearbox shall be utilized to the fullest extent.

3.2.3 Reliability

The mean-time-between-failures (MTBF, as defined by MIL-STD-721) for the integrated tail rotor servo assembly shall not be less than 2500 hours when used in the environmental extremes specified in Paragraph 3.2.5 and maintained in accordance with Paragraph 3.2.4. The mean-time-between-corrective-maintenance shall not be less than 1000 hours.

3.2.3.1 Useful Life

The integrated tail rotor servo assembly shall have a minimum total operating life of 8000 hours when subjected to the environmental extremes specified in Paragraph 3.2.5 and maintained in accordance with Paragraph 3.2.4.

3.2.3.2 Storage

The integrated tail rotor servo assembly shall have a minimum total shelf life of 5 years when stored as specified by the contractor. After such storage, the equipment shall be capable of meeting all requirements of this specification.

3.2.4 Maintainability

The fully developed, production integrated tail rotor servo assembly shall achieve the maintainability objectives stated herein. Maintainability requirements are stated for the assembly under the same conditions described for the reliability requirements (see 3.2.3 herein). Preventive and corrective maintenance tasks shall be assumed to be conducted by Army personnel with a skill level equivalent to that of an Army aircraft maintenance school graduate with 6 months of on-the-job experience. Repair tasks attributable to enemy action or operation of the equipment outside of the prescribed limits shall be excluded from the stated maintainability requirements.

3.2.4.1 Time

3.2.4.1.1 Corrective Maintenance Time (Defined by MIL-STD-721)

(a) The elapsed removal and replacement time excluding access time shall not exceed 1.5 hours using one man.
(b) Off-aircraft corrective maintenance shall not exceed 9.0 hours at the aviation intermediate maintenance level using one man.
(c) Depot-level repair shall not require more than 60.0 hours using one man.

3.2.4.2 Preventive Maintenance

3.2.4.2.1 Scheduled Removals

There shall be no scheduled removals (e.g. TBO or retirement time).

3.2.4.2.2 Inspection

(a) The frequency of preflight inspection shall average one per three flight hours.
(b) The frequency of daily inspection shall average one per three flight hours. The elapsed inspection time shall not exceed 1.0 minutes excluding time to gain access to the unit.
(c) The interval of periodic inspections shall not be less than 500 flight hours. Preventive periodic inspection tasks and required task times shall be specified by the vendor.
(d) There shall be no other preventive maintenance requirements.

3.2.4.3 Servicing

3.2.4.3.1 There shall be no required servicing tasks such as periodic lubrication, calibration, or adjustment, except for servicing of the reservoir supply.

3.2.5 Environmental Conditions

3.2.5.1 Natural Environment

The unit shall be subjected to worldwide extremes of climate and weather. Specified values for worldwide climatic extremes of temperature, humidity, rain, snow, sand and other environmental factors shall be in accordance with MIL-STD-210 and AR70-38. The operating environments shall be as specified herein for minimum operating extremes.

3.2.5.1.1 Operating Environment

When the power module is installed in the tail rotor gearbox, the combined assembly shall be capable of operating when subjected to the following environments.

3.2.5.1.1.1 Temperature

Each unit shall be capable of operation at the ambient and fluid temperatures specified below for the stated period of time. This shall include startup when the unit has stabilized at these ambient temperatures.

Ambient Temperature(°F)	Percent of Design Service Life (8000 hrs)
-65	10
-25	50
0	100
70	100
100	100
130	50
160	15

Fluid Temperature	°F
Power module fluid temperature:	-65 to 275
Gearbox lubricant temperature:	
Normal	167 ± 9
Maximum	293

3.2.5.1.1.2 Relative Humidity

The unit shall be capable of operation for the stated period of time when subjected to the following environmental conditions:

Temperature (°F)	Relative Humidity	Percent of Servo Design Service Life (8000 hrs)
70	95	65
100	95	50
130	80	30
160	20	25

3.2.5.1.1.3 Ice Conditions

The unit, when installed as intended, shall be capable of operating during and after exposure to ice, fog, hoarfrost, rime and glaze conditions.

3.2.5.1.1.4 Salt Spray

The unit, when installed as intended, shall be capable of operating during and after exposure to salt-spray conditions. No degradation in performance or life shall be in evidence for an exposure of up to 10 percent of the servo's design service life.

3.2.5.1.1.5 Fungus

The unit shall not show evidence of deterioration and shall be operable and stowable within environments containing the fungus groups described below:

Fungi Group		ATCC No.
Group I	Chactomium globosum	6205
	Myrothecium verrucari	9095
Group II	Memonomiella echinata	9597
	Aspergillus niger	6275
Group III	Aspergillus flavus	10836
	Aspergillus terreus	10690
Group IV	Pennicillium citrinum	9849
	Pencillium ochrochloron	9112

3.2.5.2 Shock

The modules, when packaged for shipment, shall be capable of sustaining a 50g shock load along any axis without requiring adjustment.

3.2.5.3 Vibration

The subject equipment shall not be damaged and shall be capable of normal operation in a vibratory environment as depicted in Figure 514.1-1, curve AT, of MIL-STD-810. The equipment shall have no resonant frequencies below 90 Hz or in the range from 800 to 1250 Hz.

3.3 Design and Construction

3.3.1 Materials, Processes, and Parts

Materials, processes, and parts shall be selected in the order of precedence set forth in MIL-STD-143. All material and material processes utilized in the construction of the servo shall meet the requirements of Chapter 6 of AMCP 706-203, the Sikorsky Aircraft Material and Process Specification Index, dated January 1972, and the Sikorsky Aircraft Preferred Parts Index, dated January 1972. If documents specified herein are in conflict, the document specifying the most stringent requirements takes precedence.

3.3.1.1 Materials

All metals used in the module's construction shall be corrosion resistant. Ferrous alloys shall have a chromium content of not less than 12 percent or shall be internally and externally protected against corrosion. Dissimilar metal protection shall be provided to those parts in direct contact. Dissimilar metals are defined in MIL-STD-889.

All springs shall be fabricated of corrosion resistant material or shall be fabricated from a material that can be tin plated in accordance with MIL-T-10727. The springs must be baked for three hours at $375 \pm 25^{\circ}F$ before and immediately after plating.

All pressure-containment parts shall be fabricated of steel, except as specifically approved by Sikorsky.

Precipitation-hardened stainless steels shall be aged at temperatures above 1025°F.

All aluminum alloys shall be of the stress-corrosion-resistant type or shall be processed to a stress-corrosion-resistant temper. Spool valves shall be fabricated of AISI 440C stainless steel.

3.3.1.1.1 Materials Properties

For design purposes, properties of materials shall be obtained from MIL-HDBK-5, MIL-HDBK-17, MIL-HDBK-23, or other sources subject to approval by the procuring activity. Allowable properties based on static and fatigue test data other than handbook data may be used subject to Sikorsky approval; properties other than those contained in the foregoing handbooks shall be substantiated and analyzed in accordance with procedures used for corresponding data in the appropriate handbook. Where it is necessary to develop data and properties for materials and composites, the test materials, processes, and composites shall be those intended for use in production. Minimum properties obtained from the foregoing sources shall be used for design purposes. In MIL-HDBK-5, "A" values shall be used in the design of structural components except that "B" values can be used for the following:

(1) "Fail-safe" or multi-redundant structures that are designed to carry full limit loads after failure of one member.

(2) Structure whose failure would have absolutely no safety of flight implications.

Where only "S" values exist, the use of such values shall require specific Sikorsky approval. Equivalent "B" values shall be derived for secondary conditions for materials where only "S" values exist, and the use of such values shall require Sikorsky approval. For substantiation of structural integrity

by analytical calculations, the nominal dimension shall be the average dimension between tolerances.

3.3.1.1.2 Corrosion

All system parts shall be treated or finished so as to provide protection from corrosion in accordance with MIL-F-7179.

3.3.1.1.3 Fatigue

Premature malfunctions caused by repeated loads shall be prevented; the methods of prevention shall include both design and manufacturing criteria as specified in 3.3.1.1.3.1 and 3.3.1.1.3.2.

3.3.1.1.3.1 Design

Fatigue analysis shall be performed in accordance with good design practice. Additional reduction factors shall be specified for analyses for unusual environments, for protective coatings (such as hard anodize and chrome plating), and for residual tensile stresses. The design analysis shall use fatigue design allowables that do not take advantage of the beneficial effects of residual compressive stresses induced by shot-peening or roller burnishing, which are applied for improved resistance to fatigue-crack initiation, and protection from fretting corrosion, for obtaining uniform production surface finishes, and for improving the fracture toughness performance of materials (i.e., avoiding stress corrosion cracking, guarding against hydrogen embrittlement cracks, and retarding fatigue crack propagation). Where applicable, optimum grain-flow orientation shall be specified on drawings. Drawing notes shall also specify Sikorsky standards to protect against improper and deleterious fabrication processing. Practices such as cold-straightening without stress relief and applications of electroplating without embrittlement-relief procedures shall be avoided.

3.3.1.1.3.2 Manufacturing

Residual tensile stresses resulting from cold-straightening shall be controlled through stress relief. In limited cases, cold-straightening or forming is allowable when applied in an intermediate (low-yield strength) temper, such as -T4 in aluminum, before final aging to limit the magnitude of residual stresses. As a minimum, surface roughness on heavily fatigue-loaded components shall be limited to 63 RMS as defined in ANS B46.1. Tool marks are not allowed deeper than 0.0001 inch if the lay of the tool mark is normal to the principal tension stress. 125 RMS is allowed when the tool mark lay is parallel to the principal (tension) vibratory stress. Application of shot-peening or other residual compressive stress-inducing processes shall not be sufficient cause for deviation from these surface roughness constraints. Residual compressive stresses shall be applied only as improvements over these minimums or as methods of protecting these minimums from service-incurred degradation.

3.3.1.1.4 Temperature Effects

The selection of allowable stresses in a design shall consider the reduction of material strength both at expected maximum temperatures and at ambient temperatures that follow exposure to elevated temperatures, maximum and minimum effects on material properties, rates of load application, and magnitudes of load. Allowable stresses shall be selected on the basis of creep, thermal expansion, joint-fastener relaxation, and fracture toughness. Elevated temperature fatigue shall be analyzed as an environmental aspect of the fatigue analysis, as dealt with in Paragraph 3.3.1.1.3.1.

3.3.1.1.5 Fracture Toughness

Resistance of a material to fracture (both static-fracture toughness and fatigue-crack propagation) will be one of the primary considerations in material choice as dictated by the material's application.

Factors that shall be considered both in the choice of materials and the processing of materials shall include, but not be limited to:

(a) Inclusions introduced during melting
(b) Tempering in the brittle temper temperature range
(c) Use of temperatures below the ductile-brittle transition temperature
(d) Excessive hardenability
(e) Microstructure
(f) Excessive coldworking
(g) Hydrogen embrittlement and stress-corrosion cracking
(h) Stress risers through design or fabrication

To facilitate adequate toughness, all damage-tolerant and fatigue-critical structural parts shall be analyzed using fracture mechanics technology.

3.3.1.2 Processes

Material properties shall not be degraded during processing so that the materials no longer meet the design specifications. In selecting or preparing a process specification, particular attention shall be given to the following:

(a) Hydrogen embrittlement that may be introduced during electro-plating, welding, or any other processing operation in which hydrogen is present.

(b) Stress corrosion that may result from improper heat treatment or the use of a metal susceptible to stress corrosion in application with a high-residual tensile stress.

(c) Joining processes that allow moisture to be drawn into a crevice, thereby promoting corrosion.

(d) Welded joints to determine that fracture toughness has not been lowered because of stress concentrations or undesirable microstructure.

3.3.1.2.1 Anodizing

All aluminum alloys shall be anodized in accordance with MIL-A-8625 for a type-II coating. A MIL-A-8625 type-I coating or a MIL-C-5541 film may be used when the part is not subject to abrasive conditions.

3.3.1.2.2 Chromium Plating

All chromium plating on piston rods or sliding surfaces shall be in accordance with QQ-C-320 type II.

3.3.1.2.3 Nickel Coating

All nickel coatings shall be applied in accordance with QQ-N-290 for nickel plating or MIL-C-2674 for electroless depositing.

3.3.1.2.4 Sub-Zero Stabilization

Close fitting sliding steel parts shall be subjected to sub-zero stabilization treatment to reduce warpage tendencies.

3.3.1.3 Parts

MS and AN standard parts shall be used where they suit the purpose intended and shall be identified on drawings by their part numbers. Government-approved standard sizes and gages shall be used where available and applicable. Sikorsky approval shall be obtained when deviating from standard parts to facilitate design, procurement or shop processing.

3.3.1.3.1 Bearings

Bearings requiring no lubrication shall be used where practical. The use of plain bearings fabricated of oil-impregnated sintered metal shall be minimized. Written notification shall be provided to the procuring activity when plain bearings fabricated of oil-impregnated sintered metal are used. Oil-impregnated bearings shall not be used in applications involving only oscillating motion.

3.3.1.3.2 Bearing Installation

Bearing installation shall not be permitted where the balls, rollers, or bearing rings are exposed to moisture, dust, or dirt. This requirement only applies to grease-packed bearings.

3.3.1.3.3 Bolts

Structural bolts that are loaded in tension shall be prestressed to minimize the effects of fatigue in the joint. Bolts smaller than one-fourth inch in diameter shall not be used in any single-bolted structural connection. MS 27575 collar-type self-retaining bolts shall be used in any joint that will require frequent disassembly for maintenance, that is a single attachment, that serves as an axis of rotation, or that is designed to transmit motion that may result in relative rotation between the components of the joint. Aluminum-alloy bolts, nuts, and screws shall not be used.

3.3.1.3.4 Bolt Threads in Bearings

The shanks of all structural bolts used in shear shall be of such length that no threads are in bearing in sheet or fittings that are equal to or less than 0.093-inch in thickness. In a thicker sheet or fitting, a maximum of two threads, including thread runout, shall be permitted in bearing when based on the maximum joint thickness and minimum bolt-grip. However, not more than 25 percent of the minimum thickness of the sheet or fitting shall have threads in bearing. For structural analysis, the total load shall be assumed to be carried by the nonthreaded portion of the bolt and by the portion of the sheet or fitting bearing on the nonthreaded portion. Where the minimum grip of the proper length bolt is slightly greater than the thickness of the material to be bolted, not more than three washers, including insulating washers, shall be used to make up the difference.

3.3.1.3.5 Pins

Flathead pins shall not be used.

3.3.1.3.6 Electrical Connectors

Electrical connectors shall conform to MIL-C-0026482.

3.3.2 Electromagnetic Radiation

The equipment shall meet the interference control requirements of MIL-STD-461.

3.3.3 Nameplates and Product Marking

A nameplate shall be securely attached to the unit housing and shall be marked in accordance with MIL-STD-130. The plate shall specify as a minimum:

(a) Manufacturer's name
(b) Manufacturer's part number
(c) Manufacturer's serial number
(d) Sikorsky part number
(e) Operating pressure.

3.3.4 Workmanship

Workmanship shall be in accordance with MIL-H-8775 and MIL-C-5503.

3.3.5 Interchangeability

The module shall be interchangeable with like modules so that adjustment will not be required on the helicopter when replacing assemblies.

3.3.6 Safety

Safety requirements for the design of the actuator shall be the safety criteria of MIL-STD-882 and MIL-E-5400, and those contained in the following paragraphs.

3.3.6.1 Personnel Safety

The module shall not present any hazard to personnel during operation, test, maintenance, installation or removal.

3.3.6.2 Overvoltage Protection

The module shall not be damaged by the abnormally high voltages specified in MIL-STD-704, Category B, and shall automatically resume operation when the voltage returns within limits.

3.3.6.3 Structure

The module stages shall be structurally isolated to prevent a crack in one stage from propagating to the other stage.

3.3.6.4 Dual External Seals

Dual seals shall be employed for piston rod seals applications.

3.3.7 Human Performance/Human Engineering

The principles and criteria of human engineering shall be applied to the design and construction of the units in accordance with the requirements of MIL-STD-1472.

3.4 Documentation

Data, if any, shall be prepared, furnished and delivered only as specified by Sikorsky Aircraft.

3.5 Logistics

Not applicable.

3.6 Personnel and Training

Not applicable.

3.7 Major Component Characteristics

3.7.1 Pumps

The module shall employ two independent, mechanically driven pumps.

3.7.1.1 Pump Pressures

The pump pressures shall be compatible with the required system pressures defined in Paragraph 3.2.1.7 herein.

3.7.1.2 Pump Rotation

Pump rotation shall be compatible with the rotation of the tail rotor's gearbox. The output shaft rotation of the tail rotor gearbox is counterclockwise when viewed from the tail rotor servo module's output end.

3.7.1.3 Pump Overspeed

The module pumps shall operate satisfactorily when subjected to speeds of 125 percent of rated speed.

3.7.1.4 Pump Rated Speed

The rated speed of the pump shall be compatible with the rated speed of the tail rotor gearbox output shaft, which is 1189 rpm at 100 percent of the main rotor speed.

3.7.2 **Reservoir**

The reservoir shall meet the requirements of MIL-R-8931 and MIL-H-8775, and shall be of a pressurized type. Pressurization may be achieved via spring force, boot strap or other methods. A common reservoir may be employed for both systems provided means exist to prevent the complete drainage of the reservoir due to a leak in one stage of the module.

3.7.2.1 **Reservoir Pressure**

The reservoir pressure shall be compatible with the inlet requirements of the system pumps for environmental and operating conditions up to 20,000 feet altitude.

3.7.2.2 **Reservoir Level Indication**

A visual reservoir level indicator shall be incorporated into the design. The indicator shall be color-coded and be visible from the ground without requiring the removal of any access covers or fairings.

3.7.2.3 **Relief Valve**

A low-pressure relief valve shall be incorporated into the reservoir to prevent inadvertent over-pressurization of the reservoir. The reservoir bleed valve may be incorporated into the design. The relief valve shall have a flow capacity compatible with the pump's maximum output capacity.

3.7.3 **High-Pressure Relief Valve**

Each hydraulic subsystem shall employ a high-pressure relief valve. The relief valve shall have a flow capacity equal to or in excess of the pump's maximum output capacity when the pump is operating at 120 percent of its rated speed. The full-flow pressure of the relief valve shall be 130 $\pm$ 2 percent of system's operating pressure. The reseat pressure shall be greater than the system's operating pressure and any pump ripple pressure spikes. The valve shall meet the requirements of MIL-V-8813.

3.7.4 Actuator Position Transducer

Four separate transducers or two dual-output transducers shall have the following performance characteristics.

3.7.4.1 General

The transducer shall be an infinite resolution, linear variable differential transformer (LVDT) type transducer with a center-tapped or split-coil output. The unit characteristics shall be determined in conjunction with the requirements of the electrical control system.

3.7.4.2 Excitation

115 VAC, 400 Hz per MIL-STD-704A, Category B.

3.7.4.3 Output Voltage

The output voltage of one coil shall vary linearly from 0 VAC (actuator retract) to 15.0 VAC (actuator extend). The output of the other coil shall vary linearly from 15.0 VAC (actuator retract) to 0 VAC (actuator extend).

3.7.4.4 Linearity

±0.1 percent of the full-scale maximum.

3.7.4.5 Output Smoothness

±0.1 percent of the full-scale maximum.

3.7.4.6 Output Impedance

600 ohms

3.7.4.7 Output Tracking Conformity

All the position transducer outputs shall track within ±0.5 percent of the full-scale maximum.

3.7.4.8 Environmental

The transducer shall be designed to be impervious to immersion in hydraulic fluid or gearbox lubricant and to withstand the specified power module operating conditions.

3.7.4.9 **Structural Capability**

The position transducer shall be designed to withstand a 100-lb force applied in any direction externally or, on its internal mechanism, in the direction of normal actuation.

3.7.5 **Pressure Transducer**

The pressure transducer shall have a center-tapped or split-coil linear variable differential transformer (LVDT) type output signal and shall be designed such that the probability of an internal failure, other than an electrical failure, is remote. The unit characteristics shall be determined in conjunction with the requirements of the electrical control system.

3.7.5.1 **Full Scale**

The full-scale differential pressure shall be the maximum value of the pressure drop across one output piston for an actuator load as defined by paragraph 3.2.1.5. In addition, an overrange capability shall be provided, if required, to be compatible with the maximum actuator cylinder pressures under all operating conditions including stall or bottoming of the output ram.

3.7.5.2 **Excitation**

115 VAC, 400 Hz per MIL-STD-704A, Category B.

3.7.5.3 **Output Voltage**

The output voltage of one coil shall vary linearly from 0 VAC (full-scale retract pressure) to 5.0 VAC (full-scale extend pressure). The output of the other coil shall vary linearly from 5.0 VAC (full-scale retract pressure) to 0 VAC (full-scale extend pressure). These output voltages may be adjusted to provide overrange.

3.7.5.4 **Output Impedance**

600 ohms

3.7.5.5 **Resolution**

As a design goal, resolution shall be infinite.

3.7.5.6 Null Output

With the pressures across the output piston being equal and with the individual cylinder pressures within the operating pressure range, the output of the transducer at 100°F (termed "INITIAL NULL") shall be 2.5 VAC ± 0.5% of full scale. Any variation in null output due to temperature changes, common mode pressure changes, or any other effects shall be limited to the following:

Fluid or Ambient Temp	Max Null Shift (from Initial Null)
-20 to +200°F	Less than ±0.5% of full scale
-65 to -20°F and 200° to 275°F	Less than ± 1% of full scale

These requirements shall hold for all environmental conditions listed in paragraph 3.2.5.

3.7.5.7 Thermal Sensitivity Shift

Less than 0.01 percent of full scale per degree Farenhiet.

3.7.5.8 Nonlinearity and Hysteresis Combined

Less than ± 0.5 percent of full scale.

3.7.5.9 Repeatability

Within ± 0.1 percent of full scale.

3.7.5.10 Vibration, Acceleration, and Shock; Combined Error

Less than 0.01 percent of full scale per g.

3.7.5.11 Absolute Error Band

The continuous plot of output voltage versus differential pressure over the operating pressure range for the environmental conditions of paragraph 3.2.5 shall have the following limits about the nominal straight-line gain curve of paragraph 3.7.5.3.

Fluid or Ambient Temp	Error Band
-20 to 200°F	Less than ± 2% of full scale
-65 to -20 and 200 to 275°F	Less than ± 3% of full scale

3.7.5.12 Response

The output signal amplitude shall be constant within ± 1.0 dB for input-pressure signals over the frequency range of 0 to 400 Hz. The phase shift between the input pressure and the output signal shall not exceed 10 degrees over that frequency range.

3.7.5.13 Operating Temperature Range

The pressure sensing device shall be capable of operating as specified herein over the ambient- and fluid-temperature ranges specified in paragraph 3.2.5.

3.7.6 Spool-Valve Position Transducer

One transducer per servo valve shall have the performance characteristics listed below. The complete unit characteristics shall be determined in conjunction with the requirements of the electrical control system.

3.7.6.1 General

The transducer shall be an infinite resolution LVDT with a center-tapped or split-coil output.

3.7.6.2 Excitation

115 VAC, 400 Hz per MIL-STD-704A, Category B.

3.7.6.3 Output Voltage

The output voltage of one coil shall vary linearly from 0 VAC (maximum actuator retract flow) to 5.0 VAC (maximum actuator extend flow). The output of the other coil shall vary linearly from 5.0 VAC (maximum actuator retract flow) to 0 VAC (maximum actuator extend flow).

3.7.6.4 Linearity

± 0.1 percent of full-scale maximum.

3.7.6.5 Output Smoothness

± 0.1 percent of full-scale maximum.

3.7.6.6 Output Impedance

600 ohms

3.7.6.7 Environmental

The transducer shall be designed to be impervious to immersion in hydraulic fluid or gearbox lubricant and to withstand the specified power module operating conditions.

3.7.7 Engage/Disengage

A two-position switching valve shall provide switching from the disengaged condition to the engaged condition upon application of supply pressure to the actuator supply port when the electrical engage signal is present. In the disengaged condition, a flow path shall be provided from one side of the output piston to the other. In the engaged condition, servo valve output shall be applied across the output piston. Complete switching shall result when the supply pressure is increased from zero to 300 psi minimum or decreased through the same range. Disengagement shall be complete within 0.02 second from the time the supply pressure reaches the disengage pressure level. Disengagement shall be complete within 0.03 second maximum from the time the electrical engage signal is removed with supply pressure present.

3.7.7.1 Shut-Off Valve

The shut-off valve shall have the following characteristics.

3.7.7.1.1 Input Voltage

Removal of the 28-VDC engage signal from the shut-off valve shall disengage the power piston. The engage signal is supplied across pins C and D of the connector (see Figure A-3) in accordance with MIL-STD-704-A, Category B.

3.7.7.1.2 Input Current

0.75 ampere maximum.

3.7.7.1.3 Disengage Response

The shut-off valve shall be designed and installed to minimize the time required to disengage the power piston.

3.7.8 Flow Control Servo Valve

The flow control servo valve shall have the following performance characteristics.

3.7.8.1 Rated Current

The rated current shall be ± 4 ma.

3.7.8.2 Maximum Current

A steady current of ± 10 ma shall not damage the servo valve or cause permanent performance changes thereto.

3.7.8.3 Flow Gain

The flow gain with negligible load pressure shall be .78 cis/ma and shall have limits consistent with the actuator velocity gain requirement of paragraph 3.2.1.6.1.

3.7.8.11 Dynamic Response

The phase lag of the servo valve operating with a load volume equivalent to that of the subject actuator shall be no more than that given by a second-order system having an undamped natural frequency of 100 Hz and a damping ratio of 0.5. This characteristic shall hold for all inputs up to ± 2.0 ma.

3.7.8.12 Repeatability

The flow-control servo valve's performance characteristics shall be repeatable throughout the useful life of the component within the limits specified herein.

3.7.8.13 Flow Limit

The maximum flow for input current greater than the rated current shall be limited to the maximum piston velocity of paragraph 3.2.1.4.

3.7.8.14 Coil Resistance

The DC resistance measured across the coil with the equipment stabilized at $77^{\circ}F$ shall be 2000 ± 200 ohms, and through the temperature range of -65 to $275^{\circ}F$, it shall be 2000 ± 500 ohms.

3.7.8.15 Coil Inductance

The coil inductance measured at the coil at 1000 Hz shall not exceed 10 henries.

3.7.8.16 Neutral Cylinder Pressure

With the electrical input signal to the servo valve at null and the differential pressure across the output piston at zero, the neutral cylinder pressure shall be 300 psi $\pm 15\%$ below the supply pressure.

3.7.9 System Bypass Signal

A switch contact closure signal shall be provided when the system pressure is lost or when the system is in bypass. The contact rating shall be 5.0 amperes minimum at 28 VDC.

3.7.10 System Filteration

The module shall include filters in each hydraulic system. Filteration levels shall be 5 microns absolute. The filters shall conform to MIL-F-8815 and shall incorporate differential pressure indicators visible from the outside of the module.

3.8 Precedence

This specification shall have precedence over all specifications referenced herein.

4.0 QUALITY ASSURANCE PROVISIONS

Intentionally omitted at this time.

5.0 PREPARATION FOR DELIVERY

Intentionally omitted at this time.

6.0 NOTES

Intentionally omitted at this time.

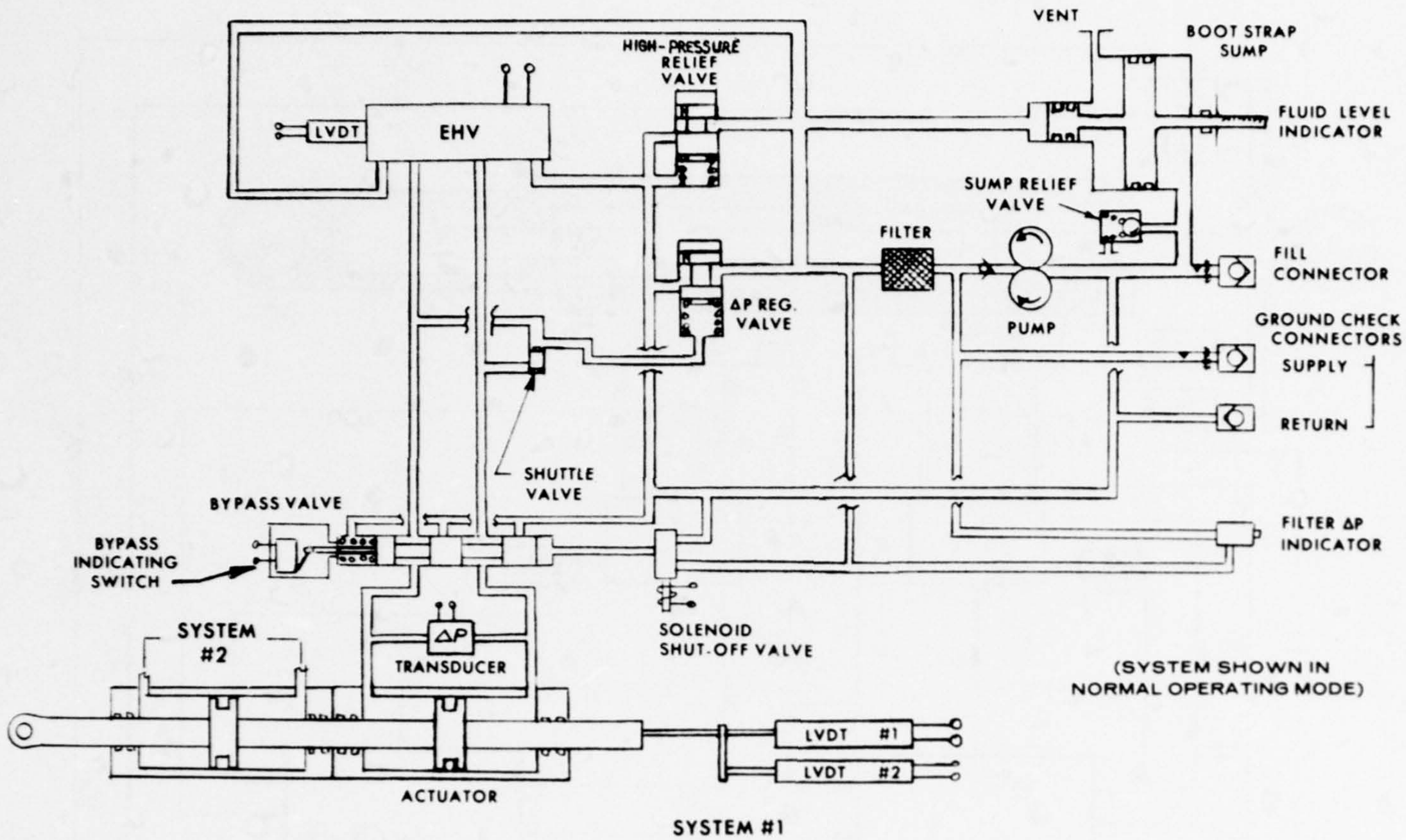

FIGURE A-1. HYDRAULIC SCHEMATIC - INTEGRATED SERVO POWER MODULE.

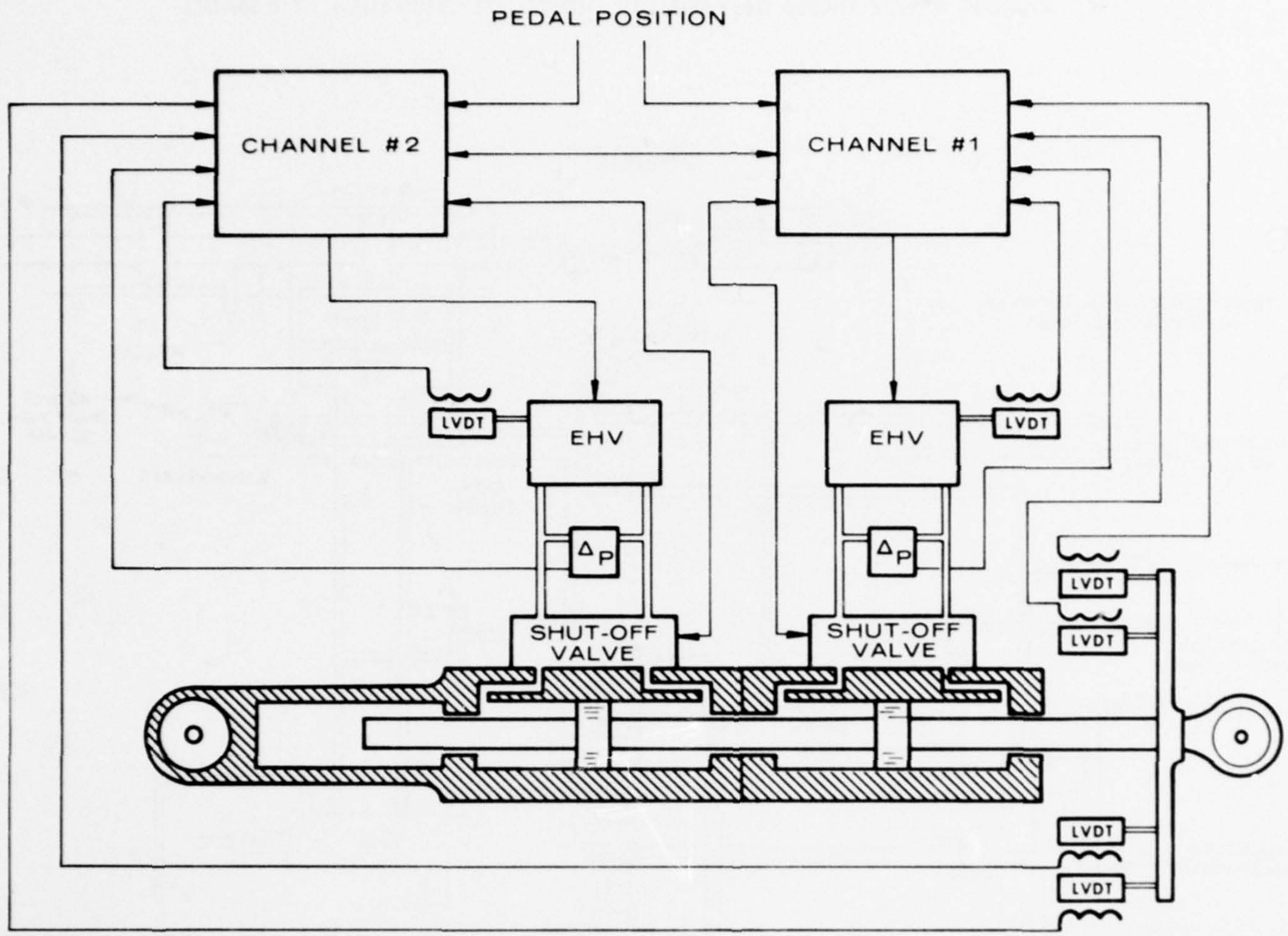

FIGURE A-2. ELECTRICAL INTERFACE BLOCK DIAGRAM.

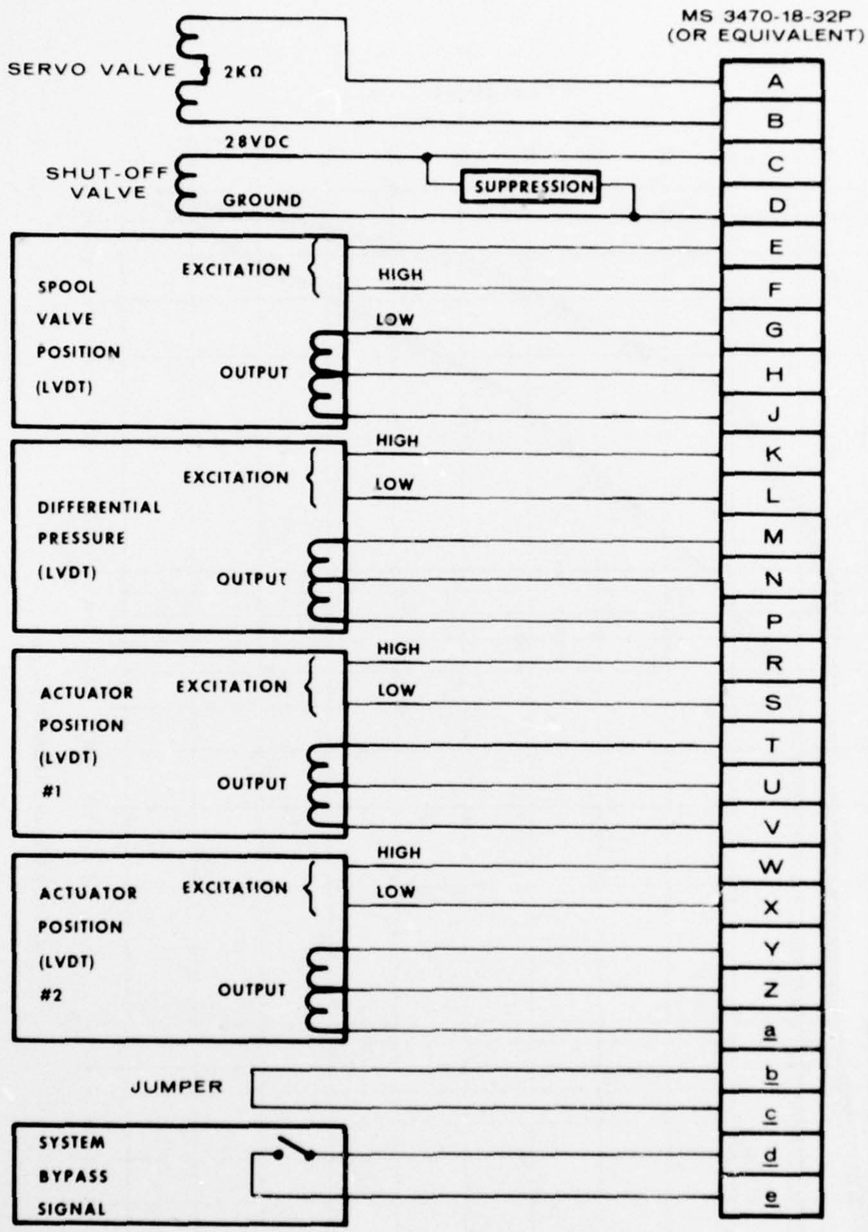

FIGURE A-3. CIRCUIT SCHEMATIC.

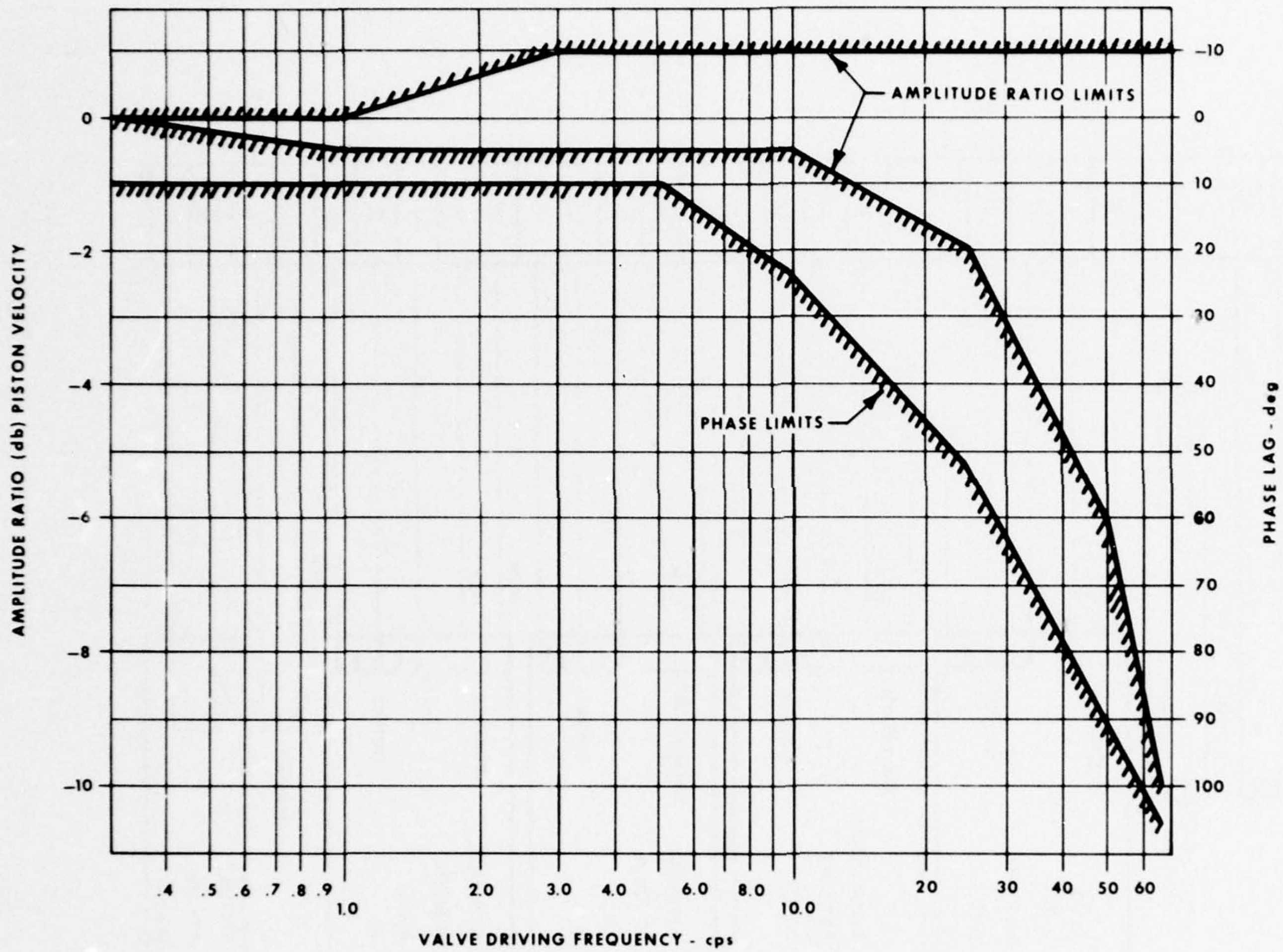

FIGURE A-4. OPEN-LOOP FREQUENCY RESPONSE REQUIREMENT.

APPENDIX B

INTEGRATED TAIL ROTOR SERVO - FLY-BY-WIRE VERSION

FAILURE MODES AND EFFECTS ANALYSIS

Included in this Appendix are the tabulated failure modes and effects for the fly-by-wire version of the integrated tail rotor servo. Also included are assessments of the criticality of each failure mode in the servo.

In the tabulations of this Appendix, the following definitions are used for the assignment of failure classification and failure probabilities.

Failure Classification	Effect
I	Safety
II	Mission Abort
III	Dynamic Component Removal
IV	Corrective Maintenance

The probability of occurrence of any system effect given on Sheet A should the failure mode being analyzed occur is indicated by:

Failure Probability Code	Probability
A	Actual effect; Prob = 1.00
B	Probable effect; 0.10<Prob<1.0
C	Possible effect; 0.0<Prob<0.10
D	No effect; Prob = 0.0

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS
SHEET A

PREPARED BY Axel Anderson
DATE 1/25/77 PAGE ____ OF ____
REVISION NO. ____ DATE ____

IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON: ASSEMBLY	FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
SK 92556-1								6.920
Boot strap sump Item (1)	2	Provide a pressurized reservoir	Piston seizure due to contamination or binding.	Reservoir pressure will not vary with pump output - it will probably drop to zero. Possible pump cavitation.	The subsystem will continue to operate on the redundant hydraulics.	None		
			Leakage Seal (1) Static and Seal (7) Static and ring due to permanent set or damage.	This will cause external leakage. A gross leak will cause the reservoir pressure to go to zero and will deplete the oil supply. Possible pump damage.	The redundant hydraulics will continue to provide the servo power function for the subsystem.	None		
			Leakage Seal (2) Static and Seal (2) Dynamic and ring and Seal (6) Dynamic and ring due to permanent set or damage.	High pressure from pump will leak to reservoir. A gross leak could reduce the hydraulic efficiency.	The redundant hydraulics will continue to provide servo nower function for the subsystem.	None		
			Leakage Seal (4) Seal (5) Due to permanent set or damage.	No effect - it would require a double failure to affect the servo power function.	If a double failure were to occur the redundant hydraulics would continue to provide the servo power function for the subsystem.	None		
			Vent clog due to contamination.					

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM	UTTAS S-70	DESIGN	DATE	PREPARED BY	Axel Anderson
SUBSYSTEM	Tail Rotor	SAFETY	DATE	DATE 2/1/77	PAGE ___ OF ___
ASSEMBLY	Servo Power Module	HUMAN FACTORS	DATE	REVISION NO.	DATE
		MAINTAINABILITY	DATE		
		ILS	DATE		

IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK-92556-1 Boot strap sump Item (1)	. Seizure of piston due to contaminants or binding	III IV			Contamination	B			Loss of redundancy
	. Leakage Seal (1) Static and Seal (7) Static with ring due to permanent set or damage.	III IV				C			Loss of redundancy
	. Leakage Seal (2) Static Seal (3) and ring dynamic Seal (5) and ring dynamic due to permanent set or damage.	III IV				B			Loss of redundancy
	. Leakage Seal (4) and (5) due to permanent set or damage.	III IV				B			Loss of redundancy
	. Vent clogs due to contamination	III IV			Contamination	B			

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS
SHEET A

PREPARED BY Axel Anderson
DATE 1/25/77 PAGE ____ OF ____
REVISION NO. ____ DATE ____

IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON			DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK-92556-1 Sump relief valve and air bleed Item (2)	2	Loosening the fitting provides a means of bleeding air from the reservoir. The sump relief valve prevents overpressuring of the reservoir by providing a check valve, which opens allowing excess pressure to vent to atmosphere.	Bleed hole clogs due to contamination.	Air would probably still bleed past the thread clearance but at a slower rate, when plug is loosened. No effect on operation.	The subsystem would continue to function.	None		0.644
			Check valve fails open or leaks due to contamination or coining or failed spring.	Hydraulic fluid would be depleted as external leakage resulting in loss of hydraulics possible pump damage.	The subsystem would continue to function. The redundant hydraulics will continue to provide the servo power function.	None		
			Check valve fails closed due to contamination or coining.	The reservoir pressure would increase with potential rupture of hydraulic chamber. Hydraulic pressure is in a direction to open the valve.	The subsystem would continue to function. The redundant hydraulics will continue to provide the servo power function.	None		
			Leakage (Static Seal) due to damage or permanent set.	Hydraulic fluid would be depleted as external leakage loss of hydraulics possible pump damage.	The subsystem would continue tn operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

DESIGN ____ DATE ____
SAFETY ____ DATE ____
HUMAN FACTORS ____ DATE ____
MAINTAINABILITY ____ DATE ____
ILS ____ DATE ____

PREPARED BY Axel Anderson
DATE 2/1/77 PAGE ____ OF ____
REVISION NO. ____ DATE ____

IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK-92556-1									
Sump relief valve and air bleed Item (2)	Clogging of bleed hole	III IV			Contamination	C			
	Check valve fails open due to contamination coining or failed spring	III IV			Contamination vibration	B			Loss of redundancy
	Check valve fails closed due to contamination or coining.	III IV			Contamination vibration	B			Loss of redundancy
	Leakage static seal due to damage or permanent set	III IV				C			Loss of redundancy

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS
SHEET A

PREPARED BY Axel Anderson
DATE 1/25/77 PAGE ____ OF ____
REVISION NO. ____ DATE ____

IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON			DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK 92556-1								48.400
Pump Item (3)	2	To provide the hydraulic pressure and flow required by the servo power module	Loss of pump output	Loss of affected hydraulic function.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
			Leakage of static or dynamic seals	Loss of fluid internal to gearbox, loss of pressure, possible pump damage.	Subsystem will continue to operate on the redundant hydraulics. Contamination of the gearbox lubricant.	No immediate affect, possible long-term damage to gearbox.		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

DESIGN ______ DATE ______
SAFETY ______ DATE ______
HUMAN FACTORS ______ DATE ______
MAINTAINABILITY ______ DATE ______
ILS ______ DATE ______

PREPARED BY Axel Anderson
DATE 2/1/77 PAGE ____ OF ____
REVISION NO. ______ DATE ______

IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK 92556-1									
Pump Item (3)	Loss of output	III IV				B			Loss of redundancy, gross leakage detected by change in gearbox or power module liquid levels.

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

SHEET A

PREPARED BY Axel Anderson
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IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON ASSEMBLY	FAILURE EFFECT ON SUBSYSTEM	FAILURE EFFECT ON SYSTEM	DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
SK 92556-1								1.932
Fill and ground check connectors Item (4)	2 sets	Fill: to provide a convenient means to fill the module and prevent back leaking.	Fails closed due to coining or contamination or screen clogs due to contamination.	Unable to fill the hydraulics.	Servo cannot be serviced. Corrective maintenance required.	Aircraft cannot be serviced.		
			Fails open due to contamination.	No consequence unless cap were left off. If cap were left off, hydraulics would cease to function due to loss of hydraulic fluid - possible pump damage.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
		Ground Check Connectors To provide a means of supplying hydraulic pressure on the ground to verify that the system is operative.	Supply Fails closed due to contamination or coining or screen clogs due to contamination.	Unable to perform ground check.				
			Fails open due to contamination.	No consequence unless cap is left off. Loss of hydraulic fluid loss of hydraulic function possible pump damage.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
			Return Fails closed due to contamination or coining.	Reservoir pressure would increase until sump relief valve opens, no consequence				
			Fails open due to contamination.	unless cap is left off. Loss of hydraulic fluid, loss of hydraulic function and possible pump damage.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

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				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK92556-1								---
Fill and ground check connectors Item (4)	2		Leakage at external seal to overboard (static) due to damage or permanent set.	The hydraulic fluid would be depleted as external leakage. Loss of hydraulic function.Possible pump damage.	The subsystem would continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

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							FAILURES	HOURS	
SK92556-1									
Fill and ground check connectors Item (4)	Fill Fail closed due to coining or contamination or screen clogs due to contamination.	IV			Contamination vibration	B			Immediate maintenance required.
	Fails open due to contamination	IV			Contamination	C			----
	Ground Check Fails closed due to contamination or coining or screen clogs due to contamination	IV			Contamination vibration	B			----
	Fail open due to contamination	IV			Contamination	C			----
	Leakage (overboard) at external seal (static) due to damage or permanent set.	IV							Loss of redundancy.

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SK92556-1								0.720
Filter Item (5)	2	Remove dirt and impurities from pump output to reduce the possibility of contamination in the system which could cause malfunction.	Clogs - due to contamination	The filter Delta P indicator would actuate. Module efficiency would degrade.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
			Leakage at inner seal (static) due to damage or permanent set.	Unfiltered oil will bypass the filter and get into the hydraulic system possibly causing an operational degration.	The subsystem would continue to operate on the redundant hydraulics.	None		
			Leakage at external seal to overboard (static) due to damage or permanent set.	The hydraulic fluid would be depleted as external leakage, loss of hydraulic function. Possible pump damage.	The subsystem would continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

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							FAILURES	HOURS	
SK92556-1									
Filter Item (5)	Clogging due to contamination	IV			Contamination	B			Loss of redundancy, detection at pre-flight; inflight detection if loss of pressure.
	Leakage at inner seal (static) due to damage or permanent set.	III IV				B			Loss of redundancy detected at pre-flight or inflight only if loss of pressure.
	Leakage overboard at external seal (static) due to damage or permanent set.	IV				B			Loss of redundancy, detection at pre-flight or detection inflight if loss of pressure.

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				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK92256-1								1.572
High Pressure Relief Valve Item (6)	2	This valve is provided to prevent over-pressuring of the servo power module.	Seizes in normal position due to contamination or binding	No effect unless pump output exceeds operating pressure. Possible damage to module due to overpressurization.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
			Relief position due to contamination or spring failure	Loss of the hydraulic function.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
			Leakage drain to return reservoir (static) due to damage or permanent set.	No effect.		None		
			Leakage supply to return (2 places)(static) due to damage or permanent set.	A gross leak could reduce module efficiency.	The redundant hydraulics will continue to provide servo power function for the subsystem.	None		
			Leakage to overboard . (static) due to damage or permanent set.	The hydraulic fluid would be depleted as external leakage loss of hydraulic function. Possible pump damage.	The subsystem would continue to operate on the redundant hydraulics.	None		

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SUBSYSTEM: Tail Rotor
ASSEMBLY: Servo Power Module

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							FAILURES	HOURS	
SK 92556-1									
High pressure relief valve Item (6)	Seizure in								
	. Normal position due to contamination or binding	III IV			Contamination	B			Loss of redundancy, detection at preflight or inflight only if loss of pressure.
	. Relief position due to contamination or spring failure	III IV			Contamination Vibration	B			Loss of redundancy, detection at preflight or inflight only if loss of pressure.
	. Leakage drain to return reservoir seal (static)	III IV				C			----
	. Leakage seal (static)(2 places) supply to return due to damage or permanent set	III IV				C			Loss of redundancy, detection at preflight or inflight only if loss of pressure.
	. Leakage to overboard seal (static) due to damage or permanent set	III IV							Loss of redundancy, detection at preflight, detection in flight if loss of pressure.

SYSTEM UTTAS S-70
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SK92556-1								
Delta P regulating Valve Item (7)	2	The valve is provided to maintain a regulated operating pressure within the operational profile of the module.	Seizes in the high diff. pressure position due to contamination or binding.	The operational pressure level will increase. If too high, the high-pressure relief valve will open (see Item 6).	The subsystem will continue to operate.			1.572
			Stays in the Low diff. pressure position due to contamination, binding or spring failure.	The operational pressure level will decrease and the hydraulics may become ineffective.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
			Leakage metered pressure to return(static) due to damage.	Gross leak could cause a shift in actuator position. If severe enough, the redundant module would take over.	The subsystem will continue to operate utilizing the redundant hydraulics.	None		
			Leakage supply pressure to return (2 places) due to damage or permanent set.	A gross leak could reduce hydraulics	The subsystem would continue to operate on the redundant hydraulics.	None		
		This valve is provided to maintain a regulated operating pressure within the operational profile of the module.	Leakage metered pressure to overboard (static seal) due to damage or permanent set.	The hydraulic fluid would be depleted as external leakage. Loss of hydraulic function. Possible pump damage.	The subsystem would continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM: UTTAS S-70
SUBSYSTEM: Tail Rotor
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							FAILURES	HOURS	
SK92556-1 Delta P Regulating Valve Item (7)	. Seizes in the High Diff. Pressure position due to contamination or binding.	III IV			Contamination	B			Loss of redundancy, detection at preflight or inflight only if loss of pressure.
	. Stays in Low Diff. Pressure position due to contamination or binding.	III IV			Contamination	B			Loss of redundancy, detection at preflight only if low pressure insufficient to move tail rotor.
	. Leakage seal (static) metered pressure to return due to damage or permanent set.	III IV				C			Loss of redundancy, detection at preflight or inflight only if severe leak.
	. Leakage supply pressure to return(2 places) due to damage or permanent set.	III IV				C			Loss of redundancy, detection at preflight or inflight only if severe leak.
	. Leakage seal (static) metered pressure to overboard due to damage or permanent set.	III IV				C			Loss of redundancy, detection at preflight, detection inflight if loss of pressure.

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				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK92556-1								
Solenoid Shut-off Valve Item (8)	2	This solenoid is provided to deactivate pressures to the actuator from the servo power module.	Stays in the normal (energized) position due to binding or contamination (the spring load is in direction to move valve to de-energized position).	The module would continue to port hi-& lo-pitch pressures to the actuator if the pump is operating. The shut-off valve would stay in normal.	If this actuator system was functioning incorrectly, redundant system would oppose causing "force-fight". Re-centering under load and loss of position control.	Possible loss of tail rotor control, mission abort.		18.848
			Stays in shut-off (de-energized) position due to power loss, open circuit, contamination or binding.	The module would not port hi-& lo-pitch pressures to the actuator.	The subsystem would continue to operate utilizing the redundant hydraulics.	None		
			Leakage overboard (static seal) due to damage or permanent set.	The hydraulic fluid would be depleted as external leakage. Loss of hydraulic function. Possible pump damage.	The subsystem would continue to operate on the redundant hydraulics.	None		
			Leakage - supply to signal (static seal) due to damage or permanent set.	No effect in normal mode (energized). If solenoid is de-energized, supply will leak to drain & hydraulic efficiency will be reduced.	The subsystem would continue to operate on the redundant hydraulics.	None		
			Leakage - signal to drain (static seal) due to damage or permanent set.	In normal (energized) mode the bypass valve may move to the shut-off position. In deenergized position, no effect	The subsystem would continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM: UTTAS S-70
SUBSYSTEM: Tail Rotor
ASSEMBLY: Servo Power Module

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							FAILURES	HOURS	
SK92556-1 Solenoid Shut-Off Valve Item (8)	. Seizure - Stays in Normal (energized) position due to binding or contamination.	III IV			Contamination	B			Detection at pre-flight. In-flight detection only if incorrect actuator operation. Immediate pilot corrective action required if accompanied by incorrect operation.
	. Seizure - Stays in Shut-Off (de-energized) position due to power loss, open circuit, contamination or binding.	III IV			Vibration	B			Detection at pre-flight or in-flight. Loss of redundancy.
	. Leakage of overboard seal (static) due to damage or permanent set.	III IV				C			Loss of redundancy. Detection at pre-flight or in-flight.
	. Leakage of seal (static) supply to signal due to damage or permanent set.	III				C			No detection.
	. Leakage seal (Static)signal to return due to damage or permanent set.	III IV				C			Loss of redundancy. Detection at pre-flight or in-flight.

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SK92556-1								
Shuttle Valve Item (9)	2	The shuttle valve has been provided to select the highest working pressure and port it to the Delta P regulating valve to maintain a desired schedule.	Stuck in either extreme due to binding or contamination.	Depending on the actuator direction, the efficiency of hydraulics may be reduced.	The subsystem would continue to operate on the redundant hydraulics.	None		0.868
			Stuck Midway -	The regulating valve would saturate and port supply toreturn, reducing the efficiency of the hydraulics.	The subsystem would continue to operate on the redundant hydraulics.	None		
			Leakage across static seal, *hi-pitch* metered pressure to overboard due to damage or permanent set.	The actuator would initially drive to *low pitch, until* position EHV saturation in opposing direction, resulting loss of force output of the affected system.	The subsystem would continue to operate on the redundant hydraulics.	None		
			Leakage across static seal between high and low metered pressure due to damage or permanent set.	The metered pressures would tend to equalize and the efficiency of the hydraulics would be reduced.	The subsystem would continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM: UTTAS S-70
SUBSYSTEM: Tail Rotor
ASSEMBLY: Servo Power Module

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							FAILURES	HOURS	
SK92556-1 Shuttle Valve Item (9)	. Seizure-Stuck in either extreme due to binding or contamination.	III IV			Contamination	B			Loss of redundancy. Detection at pre-flight only if low pressure insufficient to move tail rotor.
	. Stuck midway	III IV			Contamination	B			Same as above.
	. Leakage seal (static) Hi-Pitch metered pressure to overboard due to damage or permanent set.	III IV				C			Loss of redundancy. Detection at pre-flight only.
	. Leakage seal (static) highest metered pressure to lowest metered pressure due to damage or permanent set.	III IV				C			Loss of redundancy. Detection at pre-flight only if pressure insufficient to move tail rotor.

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SK92556-1 Delta P Transducer Item (10)	2	This transducer provides the pressure sense to the computer to verify normality and signal abnormality of the actuator hydraulic pressures.	Loss of signal due to internal failure.	Unable to maintain operational mode. with that sense.	The subsystem would continue to operate on the redundant hydraulics.	None		2.268
			Incorrect signal due to internal jam or failure.	Pressure signal will cause "force-fight" and shut-down of faulty system.	The subsystem would continue to operate on the redundant hydraulics.	None		
			Leakage overboard from Hi-Pitch metered pressure (static seal) due to damage or permanent set.	The hydraulic fluid would be depleted as external leakage. Loss of hydraulic function. Possible pump damage.	The subsystem would continue to operate on the redundant hydraulics.	None		
			Leakage Hi-Pitch metered to return (static seal) due to damage or permanent set, and leakage of Lo-Pitch metered pressure to return (static seal) due to damage or permanent set.	Hydraulic pressure scheduling may be affected, reducing the efficiency of the hydraulics.	The subsystem would continue to operate on the redundant hydraulics.	None		

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							FAILURES	HOURS	
SK92556-1 Delta P Transducer Item (10)	. Loss of Signal due to internal failure. (Open circuit - short circuit)	III IV			Vibration	B			Loss of redundancy, detection at pre-flight or in-flight.
	. Incorrect signal (Null or hard-over)	III			Contamination	C			Same as above
	. Leakage seal (static) over-board from Hi-Pitch me-tered pressure due to damage or permanent set.	III IV				C			Same as above
	. Leakage seal (static) Hi-Pitch me-tered pressure toreturn due to damage or permanent set.	III IV				C			Loss of redundancy, detection at pre-flight only if pres-sure is insufficient to move tail rotor.
	. Leakage seal (static) Lo-Pitch me-tered pressure to return due to damage or permanent set.	III IV				C			Loss of redundancy, no detection.

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				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK92556-1 Actuator Item (11)	1	The actuator provides the mechanical output to the tail rotor from the hydraulic system to effect a pitch change when called for.	Will not translate due to binding seizure from ballistic damage.	The module would remain at position of seizure - with hydraulics attempting to provide pitch change.	The subsystem would have no pitch change capability.	Loss of yaw control, mission abort.		85.862
			Failure of dual bearings (seizure).	The actuator would experience internal hardware damage.	Possible loss of pitch change capability.	Loss of yaw control, mission abort.		
			Front bearing (seizure)	The assembly would rotate on the housing instead of on the bearing.	Possible loss of pitch change capability.	Loss of yaw control, mission abort.		
			Open circuit short circuit or binding rod of LVDT.	Incorrect signal will cause fault detection and shut-down of affected hydraulic system.	The subsystem will continue to operate on the redundant hydraulic system.	None		
			Leakage of seals on transfer tubes for Hi or Low Pitch change pressure due to damage or permanent set.	There would be a loss of hydraulic efficiency. Leakage would go to gearbox.	The subsystem will continue to operate on the redundant hydraulic system.	No immediate effect, possible long-term damage to gearbox.		

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SK92556-1 Actuator Item (11) (Cont.)	1	The actuator provides the mechanical output to the tail rotor from the hydraulic system to effect a pitch change when called for.	Leakage of outer seals at outboard ends of each system actuator chambers. Leakage of inner seals at outboard ends of each system actuator chamber resulting from damage or permanent set or wear.	These seals are intended to seal low pressure therefore low pressure would leak to gearbox. If severe, the hydraulic system would lose pressure and shutdown. The seals are intended to seal high pressure. The effect is the same as above. Possible small shift in actuator position. Redundant system will prevent excessive position error.	The subsystem will continue to operate on the redundant hydraulics.	No Immediate effect, possible long term damage to gearbox due to lubricant contamination.		
			Leakage of dynamic seal separating the Hi-& Lo-Pitch pressure chamber of the actuator and leakage of static seals on rod, caused by damage, permanent set or wear.	A gross leak could cause a shift in actuator position. Possible small shift in actuator position. Redundant system will prevent excessive position error.	The subsystem will continue to operate on the redundant hydraulics.	No immediate effect, possible long term damage to gearbox due to lubricant contamination.		
			Leakage at static seals on rod separating Hi-& Lo-Pitch pressures from gearbox chambers.	A gross leak could cau[illegible] shift in act[illegible] position. The [illegible]ducer or LVDT would detect the error. Effect of oil mix TBD.	The subsystem will continue to operate on the redundant hydraulics.	No immediate effect possible long term damage to gearbox due to lubricant contamination.		

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SK92556-1								
Actuator Item (11) (Cont.)	1	The actuator provides the mechanical output to the tail rotor from the hydraulic system to effect a pitch change when called for.	Thread failure or nut backs off at front end of actuator rod.	The actuator segments would become loose.	Loss of pitch change capability.	Loss of yaw control mission abort.		
			Thread failure or nut backs off at front end of actuator sleeve.	The actuator segments would become loose.	Loss of pitch change capability.	Loss of yaw control mission abort.		
			Thread failure or nut backs off at inboard end of actuator (2 places).	The actuator segments would become loose.	Loss of pitch change capability.	Loss of yaw control mission abort.		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

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SUBSYSTEM: Tail Rotor
ASSEMBLY: Servo Power Module

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SK92556-1 Actuator Item (11)	Actuator will not translate due to binding or seizure	II III IV	Loss of yaw control		Contamination	B			Limited flight envelope, with possible high sideslip during return flight
	Failure of dual bearings (seizure)	II III IV	Loss of yaw control			B			Same as above
	Front Bearing Seizure	II III IV	Loss of yaw control			B			Same as above
	Open circuit, short circuit or binding of LVDT Rod.	III IV			Vibration	B			Loss of redundancy. Detection at preflight or in-flight.
	Leakage of seals on transfer tubes for Hi-or Lo-Pitch change pressure due to permanent set or damage.	III IV				C			Loss of redundancy. Detected at preflight only if pressure insufficient to move tail rotor.

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM UTTAS S-70
SUBSYSTEM Tail Rotor
ASSEMBLY Servo Power Module

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IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB.	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK92556-1									
Actuator Item (11) (Cont.)	Leakage of outer seals at outboard ends of each system's actuator chambers. Leakage of inner seals at the outboard end of each actuator chamber resulting from damage or permanent set or wear.	III IV				B			Loss of redundancy. Detected at pre-flight only if pressure insufficient to move tail rotor.
	Leakage of dynamic seal separating the Hi-& Lo-Pitch pressure chamber of the actuator; and leakage of static seals on rod, caused by damage, permanent set or wear.	III				B			Same as above
	Leakage at static seals on rod separating Hi-& Lo-Pitch pressures from gearbox chambers.	III				C			Same as above

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ASSEMBLY Servo Power Module HUMAN FACTORS ______ DATE ______ REVISION NO. ______ DATE ______

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IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB.	TEST EXPERIENCE FAILURES	TEST EXPERIENCE HOURS	COMMENTS
SK92556-1 Actuator Item (11) (Cont.)	Thread failure or nut backs off at front end of actuator rod.	II III IV	Loss of pitch change capability.		Vibration	C			A locking tab, washer is utilized in addition to a specified torque for tightening the nut at assembly. Limited flight envelope. Possible high sideslip.
	Thread failure or nut backs off at front end of actuator sleeve.	II III IV	Loss of pitch change capability.		Vibration	C			A locking tab washer is utilized in addition to a specified torque for tightening the nut at assembly. Limited flight envelope. Possible high sideslip.
	Thread failure or nut backs off at inboard end of actuator (2 places).	II III IV	Loss of pitch change capability.		Vibration	C			A locking tab washer is utilized in addition to a specified torque for tightening the nut at assembly. Limited flight envelope. Possible high sideslip.

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IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON			DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK-92556-1								
EHV Item (12)	2	The electrohydraulic servovalve is used to hydraulically drive the actuator as signals are received from the electronic system.	Saturates in a position to cause the Lo-Pitch metered pressure to go high; due to internal hang up of the valve or the jetpipe due to binding or contamination or faulty input signal.	The spool LVDT will sense a second stage position error Actuator hardover pressure followed by automatic shutdown due to spool LVDT.	The subsystem will continue to operate on the redundant hydraulics.	None		26.448
			Saturates in a position to cause the Hi-Pitch metered pressure to go high due to internal hang up of the valve or jetpipe due to binding, contamination or faulty input signal.	The spool LVDT will sense a second stage position error. Actuator hardover pressure followed by automatic shutdown due to spool LVDT.	The subsystem will continue to operate on the redundant hydraulics.	None		
			Leakage from supply to metered Hi-or Lo-Pitch pressure.	Error pressure would cause error in position. Severe leakage could cause loss of output force from affected system.	Subsystem will continue to operate on the redundant system.	None (see comment)		
			Does not respond to electronic input due to open circuit or no signal.	The spool LVDT will sense a second stage position error. Actuator "force-fight" followed by automatic shutdown due to spool LVDT.	The subsystem will continue to operate on the redundant hydraulics.	None		

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IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON			DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK92556-1 EHV Item (12) (Cont.)	2		Leakage to overboard at either metered pressure face seal due to damage or permanent set. or at the supply or return ports due to damage or permanent set.	The hydraulic fluid will be depleted as external leakage loss of hydraulic function possible pump damage.	The subsystem will continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

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IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB.	TEST EXPERIENCE FAILURES	TEST EXPERIENCE HOURS	COMMENTS
SK92556-1 Electro Hydraulic Valve (EHV) Item (12)	Saturates in a position to cause the Lo-Pitch metering pressure to go high, due to internal hang up of the valve or the jet pipe valve due to binding, contamination or faulty input signal.	III IV				B			Loss of redundancy. Detection at preflight or in-flight.
	Saturates in a position to cause Hi-Pitch metered pressure to go high due to internal hang up of the valve or jet pipe due to binding, contamination or faulty input signal.	III IV				B			Same as above
	Leakage from supply to metered Hi-or Lo-Pitch pressure.	III IV	See Comment						Further study required to insure this failure does not cause "force-fight" and loss of yaw control until pilot disengages affected system. Loss of redundancy. Detection at preflight only.

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

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IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB.	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK92556-1 Electro Hydraulic Valve (EHV) Item (12) (Cont.)	Does not respond to electronic input due to open circuit or no signal.	III IV			Vibration	B			Further study required to insure that this failure does not cause "force-fight" and loss of yaw control until pilot disengages affected system. Loss of redundancy. Detection at pre-flight only.
	Leakage to overboard at either metered pressure face seal due to damage or permanent set, or at the supply or drain ports due to damage or permanent set.	III IV				C			Same as above.

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IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON			DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
				ASSEMBLY	SUBSYSTEM	SYSTEM		
SK92556-1 Shut-Off and Bypass Valve Item (13)	2	This valve is designed to provide a means of shutting off the hydraulic Hi-& Lo-Pitch pressure signals and bypassing these pressures to return, in case of faulty module performance so as not to encumber the redundant module.	Valve stays in normal position due to binding, seizure, failed spring or faulty signal pressure.	The hydraulics would continue to port Hi & Lo Pitch pressures to the actuator if pumps operating. The shut off drive would not respond to a signal signifying a fault.	The subsystem would function normally. However, in event of failure of affected system, possible force-fight and loss of tail rotor control and mission abort.	None		26.596
			Valve goes to shut-off or by-pass position due to faulty signal pressure.	The regulating valve will saturate and bypass supply pressure to return. The switch will indicate the "off" condition.	The subsystem will continue to function on the redundant hydraulics.	None		
			Leakage at seal between signal pressure and return due to damage or permanent set.	The valve will go toward shut-off (see above)	The subsystem will continue to function on the redundant hydraulics.	None		
			Leakage at seal between signal pressure and Lo-Pitch pressure due to damage or permanent set.	A force bias would exist in the actuator. A loss of output force capability is possible	The subsystem will continue to operate on the redundant hydraulics.	Probably only a position error. Possible temporary loss of control fidelity until pilot can disengage faulty system.		
			Leakage at seal between Hi-Pitch pressure and return due to damage or permanent set.	The actuator would lose efficiency.	The subsystem will continue to operate on the redundant hydraulics.	None		

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IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON: ASSEMBLY	FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
SK92556-1 Shut-Off and Bypass Valve Item (13) (Cont.)	2	This valve is designed to provide a means of shutting off the hydraulic Hi-& Lo-Pitch pressure signals and bypassing these pressures to drain in case of faulty module performance so as not to encumber the redundant module.	Leakage at seal between return and overboard due to damage or permanent set.	The hydraulic fluid will be depleted as external leakage. Loss of hydraulic function. Possible pump damage.	The subsystem will continue to operate on the redundant hydraulics.	None		
			Failure of the switch due to actuating mechanism or electrical open circuit so as to not indicate an "off" condition.	The valve will continue to function but indicator will not indicate a subsequent loss of pressure or system disengagement.	The subsystem will continue to operate on the redundant hydraulics.	None		
			Failure which indicates an "off" condition.	No effect	The subsystem will continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM UTTAS S-70
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IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB.	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK92556-1 Shut-Off and Bypass Valve Item (13)	Valve stays in Normal position due to binding, seizure, failed spring or faulty signal pressure.	III IV			Vibration Contamination	B			Loss of fault detection. Detection at preflight only.
	Valve goes to Shut-off or Bypass position due to faulty signal pressure.	III IV				B			Loss of redundancy. Detection at preflight or in-flight.
	Leakage at seal between signal pressure and return due to damage or permanent set.	III IV				C			Same as above
	Leakage at seal between signal pressure and Lo-Pitch pressure due to damage or permanent set.	III IV				C			Loss of redundancy. Detection on preflight only if severe leakage.
	Leakage at seal between Lo-Pitch pressure and Hi-Pitch pressure due to damage or permanent set.	III IV				C			Loss of redundancy. Detection on preflight only if pressure insufficient to drive tail rotor.

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IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB.	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK92556-1									
Shut-Off and Bypass Valve Item (13) (Cont.)	Leakage at seal between Hi-Pitch pressure and return due to damage or permanent set.	III IV				C			Loss of redundancy. Detection on pre-flight only if pressure insufficient to drive tail rotor.
	Leakage between return and overboard.	III IV				C			Same as above
	Failure of the switch due to actuating mechanism or electrical open circuit so as to not indicate an "off" condition.	III IV			Vibration	B			Loss of fault detection. Detection at preflight only.
	Failure which indicates an "off" condition.	III IV				B			Faulty indication, possible loss of redundancy due to disengagement of a good system.

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IDENTIFICATION AND DRAWING REFERENCE	QUANTITY PER SYSTEM	FUNCTIONAL DESCRIPTION	FAILURE MODE	FAILURE EFFECT ON: ASSEMBLY	FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: SYSTEM	DEPENDENT FAILURE RESULTING FROM FAILURE MODE	FAILURE RATE PER 10^6 HOURS
SK92556-1 Filter Delta P Indicator Item (14)	2	This device provides a visual indicator to denote that the filter is clogging.	Visual indicator fails to extend.	The hydraulics will continue to operate If the hydraulic efficiency deteriorates due to lower supply pressure & flow output force capability will be lost. Bypass indicator switch will indicate severe failure only.	The subsystem will continue to operate on the redundant hydraulics.	None		1.288
			Visual indicator will not stay retracted.	No effect on hydraulic performance.	No effect.	None		
			Leakage of seal separating filter inlet and filter outlet pressure level due to damage or permanent set.	The indicator will not signal a clogged filter. Loss of filter function. Possibility of long-term system damage due to contamination.	The subsystem will continue to operate normally.	None		
			Leakage of supply pressure to overboard due to damage or permanent set of seal.	The hydraulic fluid will be depleted as external leakage. Loss of hydraulic function. Possible pump damage.	The subsystem will continue to operate on the redundant hydraulics.	None		

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS - SHEET B

SYSTEM: UTTAS S-70
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ASSEMBLY: Servo Power Module

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IDENTIFICATION AND DRAWING REFERENCE	FAILURE MODE	FAILURE CLASS	POSSIBLE SAFETY HAZARD	INDEPENDENT FAILURE CAUSING FAILURE MODE	CAUSAL ENVIRONMENT	FAILURE PROB.	TEST EXPERIENCE		COMMENTS
							FAILURES	HOURS	
SK92556-1 Filter Delta P Indicator Item (14)	Visual indicator fails to extend.	IV			Contamination	B			Loss of redundancy. Detection at pre-flight or in-flight only if pressure insufficient to move tail rotor.
	Visual indicator will not stay retracted.	IV				B			
	Leakage of seal separating filter inlet and filter outlet pressure level due to damage or permanent set.	III IV				C			Loss of filter function is not detectable.
	Leakage of supply pressure overboard due to damage or permanent set of seal.	IV				C			Loss of redundancy. Detection at pre-flight. Detection in-flight when pressure is lost.

APPENDIX C

FLY-BY-WIRE TAIL ROTOR CONTROL SYSTEM MAINTENANCE

FREQUENCIES AND REPAIR TIMES

This appendix presents maintenance data on the fly-by-wire version of the integrated servo and the electrical control system. Table C-1 presents the servo data and Table C-2 the electronics data. Electronics data was supplied by Hamilton Standard for the servo and General Electric Co, Binghampton, New York.

TABLE C-1. FLY-BY-WIRE INTEGRATED TAIL ROTOR SERVO MAINTENANCE FREQUENCIES AND CORRECTIVE MAINTENANCE TIMES

Nomenclature	Quantity	MAINTENANCE FREQUENCY (Occurrences per 10^6 Hour)					Restoration Time				
		On Aircraft			Off Aircraft		On Aircraft Removals (Elapsed Hours)			Off Aircraft (Manhours)	
		On Aircraft Removal Freq.	On Aircraft Repair Freq.	Total On Aircraft Maint. Freq.	Inter-mediate Level Maint. Freq.	Depot Level Maint. Freq.	Mean Removal Time	Maximum Removal Time	Remove Crew Size	Inter-mediate Level	Depot Level
I. Line Replaceable Unit (LRU)											
Integrated Tail Rotor Servo Power Module	1	287	N/A	287	287	N/A	0.4	0.5	2	9.0	N/A
II. Line Replaceable Components											
a. Filter Ass'y	2	.94	N/A	.04	.04	N/A	0.05 ea	0.07 ea	1	0.20 ea	N/A
b. Filter ΔP Ass'y	2	1.7	N/A	1.7	1.7	N/A	0.05 ea	0.07 ea	1	0.10 ea	N/A
c. Connections, Fill & Ground Check	6	2.5	N/A	2.5	2.5	N/A	0.05 ea	0.07 ea	1	0.10 ea	N/A
III. Shop Replaceable Components											
a. Actuator, Hydraulic	1 ass'y	N/A	N/A	N/A	103	103	N/A	N/A	N/A	1.00 total	16.0 total
b. Valve, Relief, Sump	2	N/A	N/A	N/A	.77	N/A	N/A	N/A	N/A	0.10 ea	N/A
c. Pump, Hydraulic	2	N/A	N/A	N/A	58	58	N/A	N/A	N/A	0.25 ea	5.0 ea
d. Valve, High-Pressure Relief	2	N/A	N/A	N/A	1.9	1.9	N/A	N/A	N/A	0.20 ea	5.0 ea
e. Valve, ΔP Regulating	2	N/A	N/A	N/A	1.9	1.9	N/A	N/A	N/A	0.20 ea	5.0 ea
f. Valve, Shut-off, Solenoid	2	N/A	N/A	N/A	23	23	N/A	N/A	N/A	1.00 ea	6.0 ea
g. Valve, Shuttle	2	N/A	N/A	N/A	1.0	1.0	N/A	N/A	N/A	0.20 ea	3.0 ea
h. Transducer, ΔP	2	N/A	N/A	N/A	2.7	2.7	N/A	N/A	N/A	1.00 ea	6.0 ea
i. Valve, Electro Hyd.	2	N/A	N/A	N/A	31.7	31.7	N/A	N/A	N/A	1.00 ea	10.0 ea
j. Valve, Bypass&Shutoff	2	N/A	N/A	N/A	32	32	N/A	N/A	N/A	1.00 ea	8.0 ea
k. Sump, Bootstrap	2	N/A	N/A	N/A	8.3	8.3	N/A	N/A	N/A	0.20 ea	3.0 ea

N/A = Not Applicable

TABLE C-2. FLY-BY-WIRE ELECTRONICS MAINTENANCE FREQUENCIES AND CORRECTIVE MAINTENANCE TIMES

Nomenclature	Quantity	Maintenance Frequency (Occurrences per 10^6 Hours)					Restoration Time				
		On Aircraft			Off Aircraft		On Aircraft Removals (Elapsed Hours)			Off Aircraft (Manhours)	
		On Aircraft Removal Freq.	On Aircraft Repair Freq.	Total On Aircraft Maint. Freq.	Inter-mediate Level Maint. Freq.	Depot Level Maint. Freq.	Mean Removal Time	Maximum Removal Time	Remove Crew Time	Inter-mediate Level	Depot Level
Control Unit	2	164	0	164	164	164	2.0 min.	4.0 min.	1	0.4 hr.	1.25 hr.
Control Position Transducer (CPT)	4	3	0	3	N/A	N/A	0.2 hr.	0.4 hr.	1	N/A	N/A

Assumptions

1. Replace boxes on aircraft
2. Replace circuit modules at intermediate level
3. CPT's are pre-rigged for null length
4. CPT's are nonrepairable

N/A = Not Applicable

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